# COMPUTER SIMULATION VALIDATION AND OPTIMIZATION OF QUALITY RETENTION OF CONDUCTION HEATED FOODS IN ODD SHAPED CONTAINERS

By

PIMPEN PORNCHALOEMPONG

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Dedicated to the memory of my mother Wanpen Tiraporn, to my beloved father Charn Tiraporn, and to my husband Pornchai Pornchaloempong for their unlimited and unconditional love, understanding and support. To all of my teachers with my love and respect.

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## LIST OF SYMBOLS

| | |
|---|---|
| Ar | Area of the heat transfer in radial direction $m^2$ |
| Ay | Area of heat transfer in axial direction, $m^2$ |
| $C_{avg}$ | Volume average cook value (min) |
| $C_{sur}$ | Surface cook value (min) |
| Cp | heat capacity, J /kg °C |
| $D_T$ | Decimal reduction time(min) at temperature T |
| $D_{ref}$ | Decimal reduction time(min) at reference temperature |
| $F_o$ | Sterilization Value at 121.1 °C (min) |
| h | Convective heat transfer coefficient $W/m^2$ °C |
| $h_\infty$ | Infinite convective heat transfer coefficient, $W/m^2$ °C |
| $h_T$ | Convective heat transfer coefficient on the top of the element, $W/m^2$ °C |
| $h_B$ | Convective heat transfer coefficient on the bottom of the element, $W/m^2$ °C |
| $h_R$ | Convective heat transfer coefficient on the right side of the element, $W/m^2$ °C |
| k | The first order rate constant, $s^{-1}$ |
| K | Thermal conductivity W/m °C |
| $N_o$ | The initial number or concentration |
| N | The number or concentration at time t |

| | |
|---|---|
| $(N/N_o)_{avg}$ | Volume average quality retention |
| $(N/N_o)_{sur}$ | Surface quality retention |
| Q | Rate of heat transfer W |
| $r$ | Distance in radial direction, m |
| t | Time, s |
| T | Temperature, °C |
| $T_{ref}$ | Reference temperature °C |
| $T^{p}$ | Temperature of this time step °C |
| $T^{p+1}$ | Temperature of next time step °C |
| $T_{\infty}$ | Temperature of the surrounding fluid, °C |
| U | Overall heat transfer coefficient, W/m$^2$ °C |
| V | Volume m$^3$ |
| y | Distance in axial direction, m |
| Z | Z value (°C) |
| ρ | density kg / m$^3$ |
| α | alpha thermal diffusivity (m$^2$/s) = k / ρ Cp |
| Δ | designates a difference when used as a prefix |

Subscripts

| | |
|---|---|
| i | a position index of a node in radial direction |
| j | a position index of a node in axial direction |
| i -1, j | nodes adjacent to node (i,j) to the left |
| i +1, j | nodes adjacent to node (i,j) to the right |

| | |
|---|---|
| $i, j-1$ | nodes adjacent to node (i,j) to the top |
| $i, j+1$ | nodes adjacent to node (i,j) to the bottom |

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# COMPUTER SIMULATION VALIDATION AND OPTIMIZATION OF QUALITY RETENTION OF CONDUCTION HEATING FOODS IN ODD SHAPED CONTAINERS

By

Pimpen Pornchaloempong

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Chairperson: Dr Murat O Balaban
Major Department: Food Science and Human Nutrition

Heat transfer models are effective tools for the analysis of thermal processing but their application is generally limited to simple geometries such as cylinders, rectangles and spheres. A conical and a finite elliptical cylinder are alternative shapes for products to be thermally processed. The objectives of this work were to develop heat transfer models to predict temperature distribution for conduction heated foods in any given size and shape of conically and elliptically shaped containers, to experimentally validate the models, and to use the models to predict quality or nutrient retention under different processing conditions with the goal of process optimization.

A finite difference method with energy balance approach was used for developing the models. The conically or elliptically shaped containers was divided into small volume elements  Energy balance equations were developed for each volume element and solved explicitly

An acrylic material of known thermal properties was used to manufacture different geometries and sizes of 3 cones and 2 finite elliptical cylinder  Each geometry had 3 or 4 thermocouples (36 gauge, T type) inserted at different locations  Heat penetration tests were carried out in a water bath with constant or variable water temperatures  Experimental temperatures agreed well with temperatures predicted by the models

The validated models were used to calculate lethality and quality retention under different processing conditions  All calculations were performed for a target lethality ($F_o$) of three minutes at the cold point  For a conically shaped container  the location of the cold point was searched  The effects of container geometry  food thermal diffusivity (from 1 2 to 1 6 $m^2/s$), and surface heat transfer coefficient on the retention of quality parameters were investigated. The kinetic parameters of quality attributes were the $D_{121°C}$ value (from 40 to 240 min) and the  Z value (from 10 to 60 °C) which covered the range found in the literature  The range of the retort temperature was from 110 to 140°C  The foods of high thermal diffusivity and/or foods packed in a container leading to a rapid heat transfer to the cold point required short processing times and retained more quality  Within the scope of this study  the optimum temperature for maximizing quality retention was highly dependent on the Z value of the quality factor while the D value, thermal diffusivity of food  surface heat transfer coefficient and container geometry  had minor influence on the optimum processing temperatures

# CHAPTER 1
# INTRODUCTION

Thermal processing is a popular method for the preservation of foods. It produces versatile, convenient and shelf stable products. The food is hermetically sealed in a container and heated at the proper temperature for a sufficient time to attain commercial sterility. Refrigeration after processing is usually not needed.

The heating and cooling processes are critical control points in thermal processing of low acid foods. All commercial processors in the U.S. and those in other countries that export such foods to the U.S. are required to file a process schedule for all thermally processed products to ensure safety. Generally, the target organism is the *Clostridium botulinum* which produces deadly toxin.

The calculation of the thermal process time to achieve adequate bacterial lethality is one of the few processes in the food industry which relies on a mathematical model to ensure the safety of the products. This requires knowledge of the actual transient temperature history of the food during the process by either predicting it with a heat transfer model or by actual measurement.

Heat transfer models for simulation of conduction heated foods such as canned fishes and meats, baby foods, pet foods, pumpkin, and squash require the solution of a second order partial differential equation. This can be approached by two methods analytical and numerical solutions The disadvantages of the analytical solutions are their limitations in requiring the material to conform to a regular geometry its initial temperature must be uniform, the surrounding temperature must be constant, and thermal properties are assumed constant These restrictions can be overcome by the use of numerical methods

The most common numerical method used in the analysis of heat transfer in food processing is the finite difference approach. Teixeira et al (1969) first introduced the use of the finite difference model to simulate the thermal processing of conduction heated foods packed in a cylindrical container As computer speed and capabilities increased, the model has gained popularity in thermal processing design and analysis Today it can be used to predict the product temperature history at any specified location within the container for any set of processing conditions and container size This method proved to be successful in predicting product temperature both in constant and in variable retort temperature conditions However, the finite difference model is only applied to a few regular geometries The most common shape is the finite cylinder

The recent introduction of the microwave oven for home food preparation has created a consumer demand for convenience foods in microwaveable containers, ready to reheat and serve in the package To meet this need the food industry has introduced shelf-stable prepared foods in new containers such as lunch bowls or dinner trays These containers not only provide the convenience for serving but also provide an alternate way for products to be presented which make them more appealing to the consumer Developments in food packaging regarding the shape size and materials of packages are very dynamic Since safety of the thermally processed food is crucial, thorough understanding of heat transfer behavior in any new container is needed This prompted a growing interest in the development of heat transfer models for these new shapes

The container shapes of interest in this work are conical and finite elliptical cylinder The conical container is commonly used to pack various kinds of self served foods such as ice cream, yogurt, cream etc The shape could be varied from a pointed cone to an almost finite cylinder The heat transfer model for the conical shape could not be found in the literature

The finite elliptical cylinder is commonly used to pack sardines and other seafood There are few studies of heat transfer models to elliptically shaped containers for thermal processing

The numerical heat transfer model could also be used to predict nutrient or quality retention in the food during thermal processing Conduction heated foods change their temperature slowly and display a non-uniform temperature distribution during heating and cooling The severity of heating in a container varies from the wall to its geometrical center Because of this, a high temperature short time (HTST) process will not result in maximum quality retention. A very high retort temperature will cause severe thermal degradation of the food near the surface before the center of the container has reached a desired lethality On the other extreme, a low retort temperature will cause a great loss of nutrient since long processing times are needed to obtain commercial sterility Since there are infinite time-temperature combinations which give the same bacterial lethality, the use of the heat transfer model together with calculations for nutrient retention predictions will allow the processor to optimize processing conditions for quality retention. This is cost- and time efficient because it can be achieved without requiring many experimental runs.

The climate of high competition in food marketing and the increasing demand for high quality products have increased the demand for optimization studies. Processes producing high quality products will attract a larger share of the growing health and quality conscious consumer market. A number of methods have been developed to maximize quality retention in thermal processing but these studies are limited to foods packed in finite cylindrical, rectangular and spherical containers.

The objectives of this study were to develop heat transfer models for conduction heating of foods packed in conically and elliptically shaped containers and to use the developed models for optimization of quality retention in such containers. In order to fulfill the objectives, the research was conducted in 3 phases:

1. Development of mathematical models of conduction heat transfer in conically and elliptically shaped container in response to constant or dynamic surface temperatures for predicting the content temperature at any given location in the container and at any given process time.

2. Experimental validation of the models by comparing model temperature predictions with heat penetration data, for various surface temperature conditions.

3. Use of the developed models to calculate volume average nutrient retention under various process conditions, with the goal of quality optimization.

# CHAPTER 2
# LITERATURE REVIEW

Thermal processing of foods was invented by Nicolas Appert in 1809. The method was a combination of sealing foods in a hermetic container and heating to eliminate or reduce microorganisms and /or enzymes causing deterioration or health risk.

Thermally processed foods remain popular. They provide a safe, convenient, nutritious and economical alternative to fresh and frozen foods. Shelf life of commercially sterilized foods is at least two years at room temperature.

Containers for pre-packaged thermally processed foods can be cylindrical, elliptical, pear or rectangular shaped metal containers, glass containers, retortable pouches, one-piece plastic trays, bowls or cylindrical plastic cans, etc.

Before heat transfer in thermally processed foods was well understood, the time-temperature necessary to obtain a safe product was found by trial-and-error. In 1920, Bigelow and Ball developed the first scientifically based method for the calculation of minimum safe sterilization processes for sterilization of foods in cylindrical shaped cans(Lopez, 1987). Ball (1923) proposed a graphical method to evaluate the degree of sterility of food based on the temperature history at the center of the can. Thermal processing techniques have since been well developed, making thermal processing one of the safest methods for preserving foods. Research in this area is active and continuing

The focus now are maximizing quality and retention of nutrient, more efficient production, computerized process control, more convenience and appealing packaging, and minimum energy utilization.

## Heat Transfer Models for Conduction Heated Foods

The heat transfer model for conduction heating of foods requires the solution of a second-order partial differential equation. The general equation for unsteady-state heat transfer into multi-dimensional objects is described as

$$\frac{1}{\alpha}\left(\frac{\partial T}{\partial t}\right) = \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \qquad \textit{(rectangular geometry)} \qquad (2.1)$$

$$\frac{1}{\alpha}\left(\frac{\partial T}{\partial t}\right) = \frac{1}{r}\frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial r^2} + \frac{\partial^2 T}{\partial y^2} \qquad \textit{(cylindrical geometry)} \qquad (2.2)$$

Terms are explained in the List of Symbols.

The solution can be obtained by analytical or numerical methods.

### Analytical Solutions

Many analytical solutions exist for conduction heat transfer in solids of different regular geometries such as cylinder, sphere and slab (Carslaw and Jaeger 1959). Before the computer was intensively used, a number of analytical models were developed to describe the temperature history at the slowest heating point of foods in regular shaped containers going through the sterilization process (Gillespy 1951, Hicks 1951).

Hayakawa (1969) developed a chart using an analytical method to facilitate the estimation of the heating and cooling curves at the cold point for conduction heated foods packed in cylindrical cans. Experiments were conducted to validate the model using a metal can heated in well circulating boiling water followed by cooling the can in well circulating cold water. Infinite heat transfer coefficient conditions were assumed for both heating and cooling stages. Agreement between experimental and model predicted temperatures was closer during the heating than during the cooling. This was explained by the low value of the heat transfer coefficient during cooling, which was not reflected in the model.

Analytical solutions have limitations. The container must conform to a regular geometry, initial temperature of the food must be uniform, surrounding temperature must be constant, heat transfer coefficient and the thermal properties must be uniform and constant during the process.

## Numerical Solutions

Numerical solutions are more flexible and can overcome the restrictive assumptions of the analytical solutions. They can handle problems with nonuniform initial temperature distributions, and that have temperature-dependent thermophysical properties and time-dependent boundary conditions. The numerical simulation of thermal processing of foods in a cylindrical can was first introduced by Teixeira et al. (1969). They used a finite difference method involving Taylor's expansions to find the solution of the two-dimensional partial differential equation that describes conduction heat transfer in a cylindrical can. The temperature of the food was expressed as a function of the outside temperature, the initial product temperature, the location inside the container, the thermal diffusivity of the product and the processing time The volume was subdivided into small volume elements (e g. concentric rings with rectangular cross sections for a cylinder) Every element contained a node as a reference point By assigning boundary and initial conditions to every node, the new temperature of the node is calculated after a short time interval (Δt), and the procedure is repeated until the end of process time (Teixeira, 1992)

Finite Difference Method with Energy Balance Approach

An energy balance method could be used to develop finite difference representations Instead of using the partial differential method to derive finite different equations an energy balance equation was developed for every volume element The statement of the energy balance with no energy generation is

| | | |
|---|---|---|
| The change in the internal energy of the volume element during the time interval (Δt) | = | The net heat transfer into the element during Δt |

The typical grid pattern for a finite cylinder with a convective boundary condition is shown in Figure 2 1 The temperature at each node represents the temperature at that location in the volume element

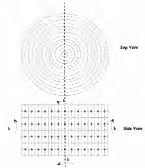


Figure 2.1 Typical grid pattern for a finite cylinder

● Capacitance nodes
○ Non- Capacitance Surface Nodes

Figure 2.2 An interior node

The interior node, i, j is surrounded by 4 adjacent nodes(Figure 2.2). The overall energy balance equation can be written as

$$\rho \, Cp \, V_{i,j} \frac{(T_{i,j}^{p+1} - T_{i,j}^{p})}{\Delta t} = \frac{k \, Ar_{(i-1,j)} (T_{i-1,j}^{p} - T_{i,j}^{p})}{\Delta r_{i-1}} + \frac{K \, Ar_{(i,j)} (T_{i+1,j}^{p} - T_{i,j}^{p})}{\Delta r_{i}} + \frac{K \, Ay_{(i,j)} (T_{i,j+1}^{p} - T_{i,j}^{p})}{\Delta y_{j}} + \frac{K \, Ay_{(i,j-1)} (T_{i,j-1}^{p} - T_{i,j}^{p})}{\Delta y_{j-1}} \qquad (2.3)$$

The energy balance equations are derived from the physical relationship of the elements. It is clear to understand and provides a meaningful check of accuracy for the derived differential equations and the resulting computer program (Clausing, 1989). The method can effectively model irregularly shaped objects, temperature-dependent properties and phase or volume change in heat conduction problems (Chau and Snyder 1988, Schreiber, 1990; Sheen and Hayakawa, 1991, Sheen et al. 1993. Erdogdu 1996 and Welt et al., 1997).

Capacitance and Non Capacitance Surface Node

Heat convection occurs whenever a surface comes in contact with fluid at a different temperature. The expression used to determine convection heat transfer rate is

$$Q = h\,A\,(T - T_{\infty}) \qquad (2.4)$$

In the energy balance approach, when the volume elements facing the convective boundary the nodes could be set as capacitance surface nodes(CSN) or non capacitance surface nodes (NCSN) (Clausing,1981) The capacitance surface nodes are nodes on the surface of volume elements with thermal mass The temperatures of the elements are changed instantly with changing outside temperature, which could result in error especially at small values of time A small element is required to reduce such error resulting in decreasing maximum time step and increasing computational time

Figure 2.3 Node(i,j) with non capacitance surface nodes on its right and bottom surfaces

The non capacitance surface nodes are the nodes on the surface of the volume element that had no thermal mass In Figure 2.3, node (i,j) has NCSN on the right and the bottom surface. Heat transfers through the surface to the node (i,j) is analyzed as a combination of resistance to heat transfer involving both convection and conduction as

$$\rho\, Cp\, V_{ij}\frac{(T_{ij}^{p}-T_{ij}^{p})}{\Delta t}=\frac{K\, Ar_{i-1/2,j}\,(T_{i-1,j}^{p}-T_{ij}^{p})}{\Delta r_{i-1,j}}+\frac{K\, Ay_{i,j-1/2}\,(T_{i,j-1}^{p}-T_{ij}^{p})}{\Delta y_{j}}+\frac{1}{\frac{1}{h_{g}\, Ar_{ij}}+\frac{\Delta r_{ij}}{K\, Ar_{ij}}}(T_{\infty}-T_{ij}^{p})+\frac{1}{\frac{1}{h_{g}\, Ay_{ij+1}}+\frac{\Delta y_{ij+1}}{K\, Ay_{j}}}(T_{\infty}-T_{ij}^{p}) \quad (2\text{-}5)$$

By setting the NCSN, accurate results are obtained and the time step restriction under high convective heat transfer coefficient condition is eliminated. The works involved with NCSN include Bellagha and Chau(1985), Chau and Gaffney(1990), Silva et al (1992 a), Erdogdu (1996), and Welt et al (1997).

Convective Heat Transfer Coefficient

The convection heat transfer coefficient (h) is a complex function of geometry, fluid flow and fluid properties. An infinite convective heat transfer coefficient with negligible surface resistance is a valid assumption when condensing steam is used to heat foods in metal containers. By this assumption, temperature of the food at the surface is equal to the temperature of the heating medium. When prepacked foods are cooled with water or heated with a steam/air mixture, a finite surface heat transfer coefficient is assumed (Tucker and Clark, 1990; Bhowmik and Tandon, 1987; Lebowitz and Bhowmik, 1989, 1990; Silva et al., 1992b).

When foods are packed in a high heat barrier material, e.g., glass, or plastic containers, the overall heat transfer coefficient (U) is used. This value is the combination of outside surface heat transfer coefficient and the thermal resistance of the packaging material (Lebowitz and Bhowmik, 1990). Sheen et al. (1993) used a U value of 700 W /m$^2$ K in the finite volume model for simulating heat transfer in apple sauce packed in a bowl shaped plastic container (5.3 mm thickness) processed in an autoclave. Lebowitz and Bhowmik (1990) determined overall heat transfer coefficients for the come-up, heating and cooling cycles of thermal processing for retortable pouches heated by circulating hot water under overriding air pressure. They found that U values for these different processing cycles were not significantly different and were within the range of 174-243 W / m$^2$ K. Since the pouch materials are very thin, they also found that U values for either aluminum/foil/polymer laminate or all plastic pouches were not significantly different.

## Application of Finite Difference Method in Thermal Processing of Irregularly Shaped Containers

There are some research on the application of finite difference methods to solve transient heat transfer problems involving irregularly shaped geometries. Manson et al. (1974) developed a 3-dimensional finite difference model for conduction heated foods in a pear shaped container. However any attempt to validate the model was not mentioned. Simpson et al. (1989) developed a 3-dimensional finite difference model to evaluate thermal processes for conduction heated foods in an oval shaped container. They used Equation 2.1 in rectangular coordinates, and the volume was subdivided into small rectangular elements. To make the grid fit the curved boundaries, a proportionality factor was applied to the nodes near the surface of the oval. In this study, the predicted temperature within the oval shape was validated with an analytical solution, but not experimentally. Chau and Snyder (1988) developed a finite different model for thermally processed shrimp using the energy balance technique with non capacitance surface node. A shrimp was approximated by a short cylinder followed by a right circular cone. A stair step approach was used to approximate the radial boundary of the cone. The volume elements were series of concentric rings stacked upon each other with each consecutive set of rings containing one less node. The experimental validations of a center temperature of a shrimp during heating and cooling were conducted in a water bath. A good agreement of experimental and simulated results was found. Sheen et al. (1993) applied finite volume method to a curvilinear boundary to develop a model for conduction heated food in a bowl shaped plastic container. An experimental validation was carried out in an autoclave using bentonite and apple sauce. They found satisfactory agreement between the model prediction and experimentally measured temperatures at two points within the bowl of bentonite solution. Erdogdu(1996) developed a finite difference model using the energy balance technique for heat transfer in an elliptical cylinder with the method of heat flowlines as suggested by Eshleman(1976) and Pham(1991). There was close agreement between experimental and simulated temperature histories at the center and an off-center point of an elliptical cylinder. He found that it is also possible to accurately predict center temperatures of an elliptical cylinder with a right circular cylinder of an equal surface area to-volume ratio when the eccentricity of the cross section ellipse < 0.7.

With increasing computer speed and capability, numerical methods have gained more popularity and have been widely used by several researchers to predict temperature distribution of conduction heated foods. Table 2.1 shows some uses of the finite difference method in thermal processing of foods.

A finite element method could also predict temperature distribution of foods during thermal processing. Although the finite element method is more flexible for irregular containers than finite difference, it requires more computer time, and is more difficult to set up. Tandon and Bhowmik (1986) developed a finite difference model for predicting temperature for conduction heated foods packaged in retortable pouches where the actual shape was considered. A proportionality factor was applied to the elements near the edge of the container. They also used the finite element method to model heat transfer in the same object. Temperature prediction validation was conducted experimentally with a bentonite solution in a retort. They found that with the same accuracy, the finite difference method required 4 times less computer time and was easier to set up.

### Application of Numerical Heat Transfer Model in Thermal Processing of Foods

Several applications of the numerical model to simulate temperature history at a given location of packed foods undergoing thermal processing are discussed by Datta et al. (1986) and Teixeira (1992). A model could predict product temperature either when the retort temperature was constant or varied in any prescribed manner throughout the process. The use of these models has become invaluable since it is not necessary to carry out repeated heat penetration tests. These models could be used for simulating the process

**Table 2.1** Heat transfer models for prepackaged conduction heated foods using finite difference method

| Reference | Geometry | h | Boundary condition | Experimental Temperature validation |
|---|---|---|---|---|
| Teixeira et al. (1969) | Cylindrical can 2D | $h_\infty$ | Step-function | |
| Manson et al. (1970) | Rectangular container 2D | $h_\infty$ | Step-function | |
| Manson et al. (1974) | Pear-shaped container 3D | $h_\infty$ | Step-function | |
| Teixeira et al. (1975) | Cylindrical can, 2D | $h_\infty$ | Step-function<br>Sinusoidal function<br>Combination of ramps single square wave | |
| Saguy and Karel (1979) | Cylindrical can, 2D | $h_\infty$ | Variable surface temperature | |
| Ohlsson (1980a) | Flat container (Infinite Slab, 1D) | $h_\infty$ | Step-function with linear come-up time | |
| Ohlsson (1980b) | Cylindrical can, 2D | $h_\infty$ | Step-function with linear come-up time | |
| Nadkarni and Hatton (1985) | Cylindrical can, 2D | $h_\infty$ | Variable surface temperature | |
| Tandon and Bhowmik (1986) | Retortable pouch<br>(The real shape is considered) | $h_\infty$ | Step Function | Bentonite solution |
| Bhowmik and Tandon (1987) | Retortable pouch<br>(The real shape is considered) | $h_{fin}$ | Step Function | Bentonite solution |
| Simpson et al. (1989) | Oval-shaped container 3D | $h_\infty$ | Step-function | |
| Hendrickx et al. (1993) | Infinite cylinder, finite cylinder sphere (1D) | $h_\infty$ | Step-function with linear come-up time | |
| Tucker and Clark (1990) | Cylindrical Plastic container<br>Rectangular polypropylene block | $h_{fin}$ | Variable surface temperature | Sylgard 184 elastomer |
| Shin and Bhowmik (1990) | Cylindrical plastic container<br>(Thermal diffusivity of the wall was considered) | $h_\infty$ | Step function | Bentonite solution,<br>Apple sauce |
| Silva et al. (1994a) | Infinite slab(1D), Infinite cylinder (1D<br>sphere 1D | $h_{fin}$ | Step-function with linear come-up time | |
| Zone et al. (1993) | Bowl shaped plastic container | $h_\infty$ | Step-function | |

conditions experienced in continuous sterilizer systems, in which containers pass from one chamber to another, experiencing a changing retort temperature at the can wall. The models could also be used to rapidly evaluate an unscheduled process deviation, such as when an unexpected drop in retort temperature occurs during processing, by predicting product center temperature in response to that variation, and evaluate a sterilizing value based on that prediction.

Another essential use of the models is to find the optimal process condition giving the maximum nutrient or quality retention while maintaining a desired safety of the product. The model for this application should be able to predict the temperature for all of the locations within the volume throughout the process, and use these data to calculate the retention of quality or nutrient. Without the use of the models, optimization of nutrient retention becomes almost impossible since it would require a series of heat penetration tests and experiments to measure the retention of the quality attributes of interest after the process.

## Effect of Heat on Thermo-labile Substances in Food

Thermo-labile factors of foods that degrade according to a first order kinetics include most microorganisms and their spores, enzymes, vitamins and other sensory quality factors (e.g. color, texture and flavor). The general equation to describe the first order degradation kinetics can be written as

$$\ln\frac{N}{N_o} = -k\,t \qquad (2.6)$$

In order to define the temperature sensitivity of the kinetic parameters, two methods are used: Arrhenius and thermal death time (TDT) methods. The Arrhenius method is based on a thermodynamic approach. The natural logarithm of reaction rate constant k is related to the reciprocal of the absolute temperature with activation energy (Ea) found from the slope of the fitted line. The method has been widely used to describe chemical kinetics.

The TDT concept, first introduced by Bigelow et al (1920), is based on an empirical approach to the temperature dependence of the first order destruction rate of microorganisms. This method has been subsequently used in numerous studies leading to its widespread application in thermal process calculations. In the TDT method, the D value is defined as the time, at a constant temperature, necessary to reduce 90% of the initial concentration. The relationship between D and k is

$$D = \frac{2.303}{k} \qquad (2.7)$$

thus

$$\ln\frac{N}{N_o} = -\frac{t}{D} \qquad (2.8)$$

Temperature of 121.1° C is commonly used as a reference temperature in thermal processing. The D value at this temperature is called $D_{ref}$. A temperature change necessary to cause a 90% change in D value is defined as the Z value. Reactions having a small Z value are highly temperature dependent, changing temperature has a great effect on changing the reaction rate On the other hand reactions with high Z values have low thermal dependency and reaction rates are less sensitive to temperature changes

The values for $D_{ref}$ and Z of some microorganisms spores and quality attributes are shown in Table 2.2 The values for a given nutrient or quality factor depend on intrinsic properties of the food (e g composition pH, water activity oxidation-reduction potential) extrinsic factors (e g gas composition inside the container) and their interactions (Silva et al 1992a) These parameters must be used in the same environment and temperature range in which the kinetic data were obtained

### Evaluation of Safety in Thermally Processed Foods

The main objective of thermal processing is to destroy spoilage and pathogenic microorganisms together with their spores or toxins in order to obtain safe and shelf-stable products. The amount of heating required depends on the resistance to heat of the microorganisms which may be present in the container on the rate of heat penetration into the "cold point" of the container and on the desired level of lethality required

### Concept of Cold Point Lethality

Bigelow et al (1920) first proposed the general method to evaluate the lethality of bacterial spores during thermal processing The calculation of lethality is based on actual product temperature at the slowest heating point (cold point) and integrates the total lethal effect of time-temperature combinations for the entire process

Total lethality is described mathematically by the $F_o$ value It is defined as time at the reference temperature (generally 121 1°C ) assuming instantaneous attainment of this

**Table 2.2** D and Z value of some microorganisms and food quality factors

| Constituent | Z (°C) | $D_{121\,°C}$ (min) | Environment | Experimental range (°C) | Reference |
|---|---|---|---|---|---|
| Vegetative cells | 4-6.6 | 0.002-0.003 | | | Lund (1977) |
| *Clostridium botulinum* Spore | 10 | 0.21 | | | |
| Spores | 6-12 | 0.1-5.0 | | | Lund (1977) |
| Enzymes | 6-60 | 1-15 | | | Lund (1977) |
| Vitamins | 25-45 | 100-1000 | | | Lund (1997) |
| Sensory quality | 23-29 | | Fish pudding | 110-134 | Ohlsson (1980c) |
| (odor, taste, consistency | 21-34 | | Liver paste | 110-134 | |
| hardness, sourness, | 19-22 | | Strained beef | 110-134 | |
| lightness) | 18-24 | | Strained vegetable | 110-134 | |
| | 18-28 | | Tomato sauce | 110-134 | |
| | 13-22 | | Vanilla sauce | 110-134 | |
| Color, Flavor | 45 | 115-157 | Mint puree | 109-149 | Torres and Oliveira (1994) |
| | 24 | 103.5 | Milk | | Torres and Oliveira (1994) |
| Lysine | 26 | 556 | Milk | | Torres and Oliveira (1994) |
| Maillard reaction | 45-55 | 271-285 | Apple juice | 38-130 | Torres and Oliveira (1994) |
| Color (Hunter scale) | 42.8 | 31.1 | Green pea puree | 110-125 | Shin and Bhowmik, 1995 |
| Chlorophyll a | 56-81 | 13.9 | Vegetable puree | 115-138 | Torres and Oliveira (1994) |
| | 52-59 | 115-166 | Vegetable puree | 79-138 | |
| Hardness | 21.3 | | White bean in brine | 90-122 | Van Loey (1995) |
| Browning | 45 | 0.98-1.08 | Goat's milk | 93-124 | Torres and Oliveira (1994) |

temperature and instantaneous cooling afterwards that would give the same degree of sterility as the process. $F_o$ value can be expressed as

$$F_0 \int_0 10^{\frac{T-T_o}{z}} dt \qquad (2.9)$$

*Clostridium botulinum* is the most important target spore forming microorganism in relation to the safety of low acid heat-processed foods. A process would be described as safe when it reduces the probability of the survival of this organism to a very small value, such as not more than one in a trillion cans ($10^{12}$) (Gillespy, 1951). Pflug and Odlaug (1978) reviewed the literature and concluded that Z = 10°C. $D_{ref}$ = 0.2 min could be used in thermal process calculations to achieve $F_o$ = 3 min. This process ensures the safety of low-acid canned foods from botulism. $F_o$ for some current commercial processes are presented in Table 2.3.

Ball (1923) derived a formula for a heat penetration curve at the center of a cylinder based on the analytical solution of conduction heat transfer. This was called the formula method. Even though the method is easier to perform manually, it has many restrictive assumptions, e.g., the heat penetration curve has to be a straight line, the heating and cooling temperature must remain constant.

**Table 2.3** $F_o$ for some current commercial processes

| Product | can size | Approximate calculated Fo (min) |
|---|---|---|
| Asparagus | All | 2 to 4 |
| Green beans, brine packed | No 2 | 3 5 |
| Green beans, brine packed | No 10 | 6 |
| Chicken bone | All | 6 to 8 |
| Corn, whole kernel, brine packed | No 2 | 9 |
| Corn, whole kernel, brine packed | No 10 | 15 |
| Cream style corn | No 2 | 5 to 6 |
| Cream style corn | No 10 | 2 3 |
| Dog food | No 2 | 12 |
| Dog food | No 10 | 6 |
| Mackerel in brine | 301 x 411 | 2 9 to 3.6 |
| Meat loaf | No 2 | 6 |
| Peas, brine packed | No 2 | 7 |
| Peas brine packed | No 10 | 11 |
| Sausage, Vienna, in brine | Various | 5 |
| Chili con carne | Various | 6 |

Source Lopez (1987)

With the progresses that have evolved in computer technology, the evaluation of target $F_o$ by the general method has become more popular due to its versatility. Computer programs available commercially require only time-temperature data at the cold point to evaluate target lethality automatically.

Position of the Cold Point

The position of the cold point of food undergoing thermal processing is crucial for lethality calculation. The $F_o$ value at the cold point is attributed to the whole container, on the principle that a process which is safe for the point of slowest heating must be safe for the whole container. Inaccuracy in locating the position of the cold point may result in under-processing. The position of cold point for convection and conduction heated foods is different. Agitation or rotation of a container during processing also affects the cold point position.

The cold point for conduction heated foods with no agitation, packed in symmetrical shaped containers made from one uniform material, e.g., cylinder, rectangular or elliptically shaped metal can as well as aluminum retortable pouch, is at the geometrical center. This is not true for asymmetrical shapes such as pear, bowl or cone, or a container made of more than one material, such as, a plastic can with a metal lid. Sheen et al. (1993) found that the cold point of a bowl-shaped container with a metal lid (top radius = 42 mm, bottom radius = 28 mm, height = 57 mm, with curved boundary) during heating in a circulated superheated water-type retort was located at a fraction of 0.46 of the height of the container from the bottom, on the rotation axis. The cold point moved slightly toward the bottom during cooling with water due to changing heat transfer coefficient. Berry and Bush (1988) reported that the cold point of conduction heated food in a cylindrically shaped plastic container with the metal lid up during processing was slightly below the center of the can.

Processing conditions and thermophysical properties of foods also affect the position of the cold point. Naveh et al. (1983) developed a conduction heat transfer model for a product packed in a glass jar with head space. They found the products of high thermal diffusivity had a slight shift in the location of the cold point towards the head space.

## Concept of Volume Average Lethality

During a thermal process, the severity of a thermal process in a conduction heated food decreases going from the geometrical center to the wall of the container. Stumbo (1953) proposed a method to evaluate volume-average bacterial spore retention. He described this gradient of severity by picturing a series of imaginary nested containers inside the real container. These containers were considered to be cylindrical in shape and decreasing in size from the wall to the geometrical center of the real container and the severity of heating was the same at all points in these containers. He called them iso-j regions. The temperature history during thermal processing for one point of each iso-j region was calculated by an analytical method. The bacterial spore retention corresponding to that point or its iso-j- region was evaluated by the general method for thermal process calculation. The spore retention was then integrated. This method is impractical since the determination spores less than 1 in $10^5$ containers is very difficult(Pflug and Odlaug, 1978). However, the concept became valuable since it could be applied to determine the retention of any heat labile component in food, e.g. nutrients, sensory qualities, which follow first order rate of destruction.

Volume Average Quality Retention

Ball and Olson (1957), Jen et al (1971), and Barreiro et al (1984a) extended the volume average concept to develop manual methods for estimating nutrient degradation in conduction heated foods in cylindrical and rectangular containers. The methods require constant processing temperature and the linear heat penetration curve is assumed.

When Teixera et al (1969) introduced a finite difference model to predict temperature at any location at any given time in the containers during thermal processing, they combined the model with the volume average concept to estimate bacterial spore and thiamine retention after processing. By dividing the overall volume into small volume elements, the retention after a small time interval Δt can be written as

$$N_{(t+\Delta t)} = N_t \, 10^{(-\Delta t / D_T)} \qquad (2.10)$$

where $N_t$ and $N_{t+\Delta t}$ are the number or concentration at time t, and after a short time interval (Δt), respectively. $D_T$ is a decimal reduction value which is temperature-dependent and will be updated with temperature change as

$$D_T = D_{ref} \, 10^{\frac{(T_{ref} - T)}{z}} \qquad (2.11)$$

The overall retention is calculated at the end of the process by summing the number of spore or concentration of quality retention of each volume element over the container. The volume average retention is defined as

$$\left(\frac{N}{N_o}\right)_{avg} = \frac{1}{V}\int_0^V 10^{-\frac{1}{D_{ref}}\int_0^t 10^{\frac{T(t)-T_{ref}}{z}} dt} dV \qquad (2.12)$$

This method could be used for both constant and variable retort temperatures.

Average Cook Value

Another parameter associated with quality retention is the cook value (C value). It is similar to the $F_o$ value concept which is based on a temperature resistance value Z. The most common reference temperature used to calculate the C value is 100°C.

$$C_{avg} = \int_0^t 10^{\frac{T(t)-100}{z}} dt \qquad (2.13)$$

Similar to overall nutrient retention, the volume average cook value is defined as

$$C_{avg} = \frac{1}{V}\int_0^V \int_0^t 10^{\frac{T(t)-100}{z}} dt\, dV \qquad (2.14)$$

## Optimization in Thermal Processing

The optimization in thermal processing requires the identification of a process variable that can be controlled, the requirements that must be met (the constraint), and an objective function (Norback, 1980). The constraint for optimizing the heat sterilization process is the target lethality value ($F_o$) which is required to obtain a safe product.

Several objective functions have been considered in attempts to optimize heat sterilization processes. Barreiro et al. (1984b) determined an optimal temperature to process canned pea puree while minimizing energy utilization in a batch retort, while maintaining the same lethality value. However, foods that are processed based on minimum energy utilization may result in poor, unacceptable quality. Therefore, the aim of thermal process optimization is moving toward obtaining maximum nutrient and/or quality retention (Hendrickx et al., 1993).

Microorganisms and their spores are much more heat sensitive than nutrients and sensory factors (Lund, 1977). In liquid or semi-liquid products which have uniform temperature distribution during heating and cooling, the High Temperature Short Time (HTST) process or even the more extreme Ultra High Temperature (UHT) process results in higher nutrient retention. However, these processes could not be applied to conduction heated foods (e.g. tuna, ham, salmon, pork and beans, corned beef and canned pumpkin) due to non-uniform temperature distribution. Very high temperatures will cause severe thermal degradation of quality/nutrients near the container wall long before the food at the center of the container has risen in temperature. On the other extreme, a relatively low retort temperature will also cause great quality loss because of the long times necessary to achieve sterility (Thijssen et al. 1978).

There is an infinite number of time- temperature combinations to achieve a desired lethality. These combinations result in different nutrient and quality retention. Therefore optimization of processing conditions is needed to obtain good quality products.

Choice of an Objective Function to Maximize Quality Retention

Two objective functions are commonly used to obtain optimal thermal process conditions to maximize quality retention, maximizing volume average retention, or minimizing cook value. These could be used for overall volume ( $N/N_{o,ave}$ or $C_{ave}$) and/or surface ( $N/N_{o,sur}$ or $C_{sur}$) of the container. Table 2.4 presents different objective functions found in the literature.

Factors Affecting Optimum Process Temperature

Container Shape, Size and Material

Teixeira et al. (1975) used a computer model to predict thiamine retention in different height-to-diameter ratios and found that retentions greater than 60% were achieved for cans with height-to-diameter ratio less than 0.2 and those with ratios greater than 10.0. A minimum retention of about 40% occurred with ratios around 1 (standard size cylindrical cans).

In flat containers such as retortable pouches or trays heat will transfer faster than in a cylindrical can with equivalent volume. Higher optimum sterilization temperatures and

Table 2.4 Studies on optimization of quality factors

| Reference | Constraint | Objective Function | Geometry | Type of Solution | Boundary condition | Method |
|---|---|---|---|---|---|---|
| Teixeira et al. (1969) | VAM | $(N/No)_{ave}$ | finite cylinder | numerical, h=∞ | constant | numerical |
| Teixeira et al. (1975) | VAM | $(N/No)_{ave}$ | finite cylinder | numerical, h=∞ | variable | numerical |
| Thijssen et al. (1978) | VAM | $(N/No)_{ave}$ | finite cylinder sphere rectangular | analytical h= $h_{finite}$ | constant | numerical |
| Saguy and Karel (1979) | VAM | $(N/No)_{ave}$ | finite cylinder | numerical, h=∞ | Variable | Pontryagin s maximum principle |
| Ohlsson (1980a) | Fo | $C_{ave}$, $C_{surf}$ | infinite Slab | numerical, h=∞ | constant | numerical |
| Ohlsson (1980b) | Fo | $C_{ave}$, $C_{surf}$ | finite cylinder | numerical, h=∞ | constant | numerical |
| Thijssen and Kochen (1980) | VAM | $(N/No)_{ave}$ | finite cylinder sphere rectangular | numerical, h=∞, $h_{finite}$ | variable | numerical |
| Nadkarni and Hatton (1985) | VAM | $(N/No)_{ave}$ | finite cylinder | Numerical | variable | maximum principle of numerical control theory |
| Hendrickx et al. (1990) | Fo | $(N/No)_{ave}$ | infinite cylinder<br>finite cylinder sphere | Analytical ,h=∞ | constant | Davies, Swann and Campey |
| Hendrickx et al. (1993) | Fo | $C_{surf}$ | infinite cylinder<br>finite cylinder sphere | numerical, h=∞ | variable | Davies, Swann and Campey |
| Tucker and Holdsworth (1991) | Fo | $C_{ave}$ | rectangular container | numerical, $h_{finite}$ | constant | numerical |
| Silva et al (1992b) | Fo | $C_{surf}$ | infinite slab<br>infinite cylinder sphere | numerical, $h_{finite}$ | constant | Davies, Swann and Campey |
| Banga et al. (1991) | VAM and Fo | $(N/No)_{ave}$ and $(N/No)_{ave}$ | finite cylinder | numerical, h=∞ | constant and variable | ICRS/DS |
| Sablani et al. (1995) | Fo | $C_{av}$(Tref = 121.1) | finite cylinder | numerical, h=∞ | constant | neural network |

VAM = Volume Average Microorganisms

better surface and average quality retention are achieved (Ohlsson 1980a Silva et al 1994a)

Packaging materials have an important role in the rate of heat transfer into the containers and therefore nutrient retention after processing Berry and Bush (1988) and Lu et al (1991) studied the rate of heat penetration into two piece, cylindrically shaped plastic containers with metal lids in comparison to metal cans of equal dimensions They found that the rate of heat penetration into the plastic containers was lower and quality retention was poorer

### Z value

The thermal resistance or Z value has a significant effect on optimal processing temperature when trying to maximize average retention or minimize average cook value of quality factors in conduction heated foods Quality factors with high Z values require high-temperature-short-time processes. This is in contrast to those of lower Z values where low temperature long time process is preferred (Teixeira et al 1969 Ohlsson, 1980b Silva et al., 1992a)

### $D_{ref}$ value

Teixeira et al (1969) studied the effect of varying the $D_{ref}$ value from 146 6 to 188 37 to 202 3 min on the optimal temperature of pea puree and concluded that this variable was not significant They found that the higher $D_{ref}$ value simply increased the percent retention. However, they considered only a narrow range of $D_{ref}$, and this range does not include the $D_{ref}$ values for sensory quality factors (10 to 50 min) Silva et al.

(1992a) extended the range of $D_{ref}$ values (between 5 and 1000 minutes) and they found that $D_{ref}$ less than 150 min has a significant effect on optimal temperature The quality factors with low $D_{ref}$ prefer high optimal temperature short time processes They also stated that the use of volume average cook value which does not take into account $D_{ref}$ may result in underestimation of optimal processing temperature

Optimization Method

Most optimal sterilization processes have been determined manually (Teixeira et al 1969 1975, Ohlsson, 1980a Thijssen and Kochen, 1980 Tuker and Holdsworth 1990 Hendrickx et al. 1992) The final quality retention is calculated for different constant temperatures or temperature profiles and plotted as a function of the design variable The optimum condition is obtained by graphical observation (Silva et al 1993)

In 1979, Saguy and Karel were the first to introduce a formal optimization theory to obtain maximum quality retention They applied the continuous maximum principle of Pontryagin and a multi iterative method to determine the best time-temperature profile in order to optimize thiamine retention in thermal processing Nadkarni and Hatton (1985) used the maximum principle of optimal control theory with the goal of optimizing the nutrient retention for a given reduction of microorganisms. Silva et al (1992b) used the Davis, Swann and Campey method to calculate optimal constant temperatures

Hendrickx et al. (1990) used an empirical approach to calculate optimal temperatures for maximizing surface cook value with infinite surface heat transfer coefficients for one dimensional shapes (infinite slab, infinite cylinder and sphere) Using traditional regression analysis, they developed empirical equations to relate optimal temperatures to various product properties (thermal diffusivity and Z-value of quality factors), processing conditions (geometry and dimensions of the food, surface heat transfer coefficient, initial product temperature and retort come up time) and processing criteria (target $F_o$ value). Hendrickx et al. (1993) extended the correlations for more generalized conditions accounting for cooling lethality as well as retort come up time. They found that heating medium come up time and the initial product temperature have a minor effect on the optimal processing temperature. Silva et al (1992b) presented the correlations for optimal sterilization temperature for conduction heated foods with finite surface heat transfer coefficients. Sablani (1995) applied a neural network approach to compute optimal sterilization temperature and their corresponding processing time for finite cylinder cans.

Experimental Validation of Quality Retention

Some experiments have been conducted to validate the quality prediction models. The validation requires the selection of a quality parameter, the kinetic data for this parameter, heat penetration characteristics in a filled container and processing using different sterilization temperatures ( Silva et al.,1994b).

The selected quality parameters for validation tests included surface lightness of tuna (Banga,1993), Hunter color scale values of pea puree (Shin and Bhowmik, 1995) and acid catalyzed sucrose hydrolysis in bentonite solution (Silva et al. 1994b). The accuracy of the predictions relies on the accuracy of predicting the temperature at each and every position during the heating and cooling process and on the accuracy of the kinetic data

The objectives of this study were to develop conduction heat transfer models for elliptical and conical shaped containers, and apply the models for thermal processing to estimate quality retention To achieve the objectives, the steps taken were to develop the models using the finite difference method based on the energy balance approach to evaluate the accuracy of the models, the temperature distributions within a cylinder were simulated with the developed finite elliptical and conical models and the results compared to those obtained from the validated numerical finite cylindrical model For the experimental validation, acrylic rods cut into various shapes and sizes of cone frustum and finite elliptical cylinder were fitted with thermocouples to measure interior temperatures at various locations. The experiments were carried out under constant and variable outside temperature environments Experimental temperatures at different locations were compared to simulated temperatures

The validated models were applied to calculate the volume integrated quality retention. The influences of the surface heat transfer coefficient, the thermal diffusivity of food, and the different container geometry and size on the retention of quality factors with different kinetic parameters( $D_{ref}$ and Z) values were investigated The goal of the investigation was to optimize the quality of the food

# CHAPTER 3
# MATERIALS AND METHODS

## Development of the Numerical Heat Transfer Models

The finite difference method, based on energy balance approach, was used to develop conduction heat transfer models in foods contained in conically and elliptically shaped containers

Basic assumptions of the models include

- Heat transfer into the food is by pure conduction
- The food product is homogeneous and isotropic i e its properties are constant with location and temperature
- The initial temperature of the food is uniform.
- The surface heat transfer coefficient can be finite or infinite

The first step in developing the heat transfer model is to divide the overall volume into small volume elements A node is assigned to every volume element as a reference point and is normally located at the center of the element The temperature at the node location is the temperature at that location in the volume element. Each element has imaginary boundaries around the node and the resulting grid forms a continuous network throughout the volume The geometrical properties of the elements for the entire region are required to develop energy balance equations These are distance between adjacent nodes, the volume of the element surrounding each node, and the area of heat transfer for the node. The following properties are also needed thermal conductivity density, and heat capacity of the food, surface heat transfer coefficient, and outside temperature. The next step is to develop an energy balance equation for every element. It was assumed that heat was transferred perpendicularly into a node from 2 directions radial and axial According to the definition of Clausing (1987), the interior nodes are defined as capacitance nodes They have a volume and heat capacity The nodes at the surface may be capacitance or non-capacitance nodes The nodes with similar geometry and boundary condition are grouped together to facilitate computer coding

In this study an explicit solution was used to calculate the nodal temperatures using the energy balance equations The temperature after a small time step depends on the temperatures before this time step The maximum time step is limited by the second law of thermodynamics Therefore it is necessary to develop the equations for calculating the maximum time step

Grid Generation in a Cone Frustum

The dimensions of a cone frustum are given as big radius (R), small radius (r) and height (H) The cone is subdivided into a series of concentric rings stacked on top of each other(Figure 3 1) The volume elements at the side surfaces have a shape of triangular cross-section ring. The number of volume elements increase by one for every axial level Because of the axial symmetry, only one-half of it will be considered As shown in Figure 3 2, nodes are at the center of every volume element as a reference point, except for the

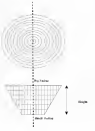


Figure 3 1 Grid generation in a cone frustum

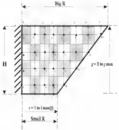


Figure 3.2 Volume element definitions in a cone frustum

● Capacitance nodes

○ Non capacitance surface nodes

nodes at the surface The interior nodes are capacitance nodes The nodes on the top and bottom surfaces are non-capacitance surface nodes while nodes on the side surfaces of the cone are capacitance surface nodes The number of nodes in the R-r region equals to number of nodes in height (not including non-capacitance surface nodes) The expressions of distances between nodes, areas of heat transfer and nodal volume are presented in Appendix A

Energy Balance Equations

Ten different types of nodes were generated within a cone frustum as shown in Figure 3 2 Energy balance equations and the calculated maximum time steps for the volume elements were as follows

Node Type 1

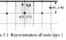


Figure 3 3 Representation of node type 1

Specification

This node is a non-capacitance surface node (NCSN) having no volume It is located at the top surface(Figure 3 3) Heat convects from the top surface boundary into the node and conducts to the node at the bottom Since heat can not be stored in the node, its energy balance equation is written as

$$h_T \Delta y_{i,j} (T_\infty^P - T_j^P) = \frac{K \Delta y_{i,j+1}}{\Delta y_{j+1}} (T_j^P - T_{j+1}^P) \tag{3.1}$$

The temperature of the node is

$$T_{i,j}^P = \frac{K \Delta y_{i,j+1} T_{j+1}^P + h_T \Delta y_j \Delta y_{i,j+1} T_\infty^P}{K \Delta y_{i,j+1} + h_T \Delta y_{i,j} \Delta y_{i,j+1}} \tag{3.2}$$

There is no need to calculate a maximum time step for this type of node

Node Type 2

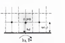


Figure 3 4 Representation of node type 2

Specification

This node is a NCSN similar to node type 1 except it is located at the bottom surface (Figure 3 4) The temperature of the node can be written as

$$T_j^P = \frac{K \Delta y_{i,j} T_{i,j+1}^P + h_B \Delta y_{i,j} \Delta y_{i,j} T_\infty^P}{K \Delta y_{i,j} + h_B \Delta y_{i,j} \Delta y_{i,j}} \tag{3.3}$$

Node Type 3

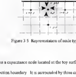


Figure 3 5 Representation of node type 3

Specification

This node is a capacitance node located at the top surface The top of the node is a NCSN with convection boundary It is surrounded by three capacitance nodes (Figure 3 5) The energy balance equation for this node is

$$\rho\, Cp\, V_{ij} \frac{(T_{ij}^{p+1} - T_{ij}^{p})}{dt} = \frac{K\, \Delta r_{i-1j}\,(T_{i-1j}^{p} - T_{ij}^{p})}{\Delta r_{ij}} + \frac{K\, \Delta r_{ij}\,(T_{i+1j}^{p} - T_{ij}^{p})}{\Delta r_{ij}} + \frac{K\, \Delta y_{ij}\,(T_{ij-1}^{p} - T_{ij}^{p})}{\Delta y_{j}} + \frac{K\, \Delta y_{ij+1}\,(T_{ij+1}^{p} - T_{ij}^{p})}{\Delta y_{ij+1}} \tag{3 4}$$

It is possible to substitute $T^{p}_{i\ j+1}$ in equation 3 4 with equation 3 2 Since the reference node is now node type 3, the equation 3 2 is then changed to

$$T_{ij+1}^{p} = \frac{K\, \Delta y_{ij}\, T_{ij}^{p} + h_T\, \Delta y_{ij+1}\, \Delta y_{ij}\, T_{\infty}^{p}}{K\, \Delta y_{ij} + h_T\, \Delta y_{ij+1}\, \Delta y_{ij}} \tag{3 5}$$

After substituting thermal diffusivity ( $\alpha = \dfrac{K}{\rho\ Cp}$ ) and solving for the nodal temperature in the next time step ( $T^{p+1}$ ) the corresponding equation becomes

$$\begin{aligned} T_{i,j}^{p+1} = {} & \frac{\alpha\ \Delta t\ \ Ar_{i-1,j}}{V_{i,j}\ \Delta r_{i-1,j}}\ T_{i-1,j}^{p} + \frac{\alpha\ \Delta t\ \ Ar_{i,j}}{V_{i,j}\ \Delta r_{i,j}}\ T_{i+1,j}^{p} \\ & + \frac{\alpha\ \Delta t}{V_{i,j}\left( \dfrac{K}{k_T\ Ay_{i,j-1}} + \dfrac{\Delta y_{i,j}}{Ay_{i,j}} \right)}\ T_{\infty}^{p} + \frac{\alpha\ \Delta t\ \ Ay_{i,j+1}}{V_{i,j}\ \Delta y_{i,j+1}}\ T_{i,j+1}^{p} \\ & + \Bigg( 1 - \frac{\alpha\ \Delta t\ \ Ar_{i-1,j}}{V_{i,j}\ \Delta r_{i-1,j}} - \frac{\alpha\ \Delta t\ \ Ar_{i,j}}{V_{i,j}\ \Delta r_{i,j}} \\ & - \frac{\alpha\ \Delta t}{V_{i,j}\left( \dfrac{K}{k_T\ Ay_{i,j-1}} + \dfrac{\Delta y_{i,j}}{Ay_{i,j}} \right)} - \frac{\alpha\ \Delta t\ \ Ay_{i,j+1}}{V_{i,j}\ \Delta y_{i,j+1}} \Bigg) T_{i,j}^{p} \end{aligned} \tag{3.6}$$

In order not to violate the second law of thermodynamics, the coefficient of the last term ( $T^{p}_{i,j}$ ) in equation 3.6 has to be greater than 0. By setting coefficient of ( $T^{p}_{i,j}$ ) $\geq 0$ , the nodal maximum time step yields

$$\Delta t_{i,j} \leq \frac{V_{i,j}}{\alpha\left( \dfrac{Ar_{i-1,j}}{\Delta r_{i-1,j}} + \dfrac{Ar_{i,j}}{\Delta r_{i,j}} + \dfrac{1}{\dfrac{K}{k_T\ Ay_{i,j-1}} + \dfrac{\Delta y_{i,j}}{Ay_{i,j}}} + \dfrac{Ay_{i,j+1}}{\Delta y_{i,j+1}} \right)} \tag{3.7}$$

Node Type 4

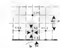


Figure 3 6 Representation of node type 4

Specification

This node is a capacitance node similar to node 3 except it is located at the bottom (Figure 3 6) The temperature for the node at the time step ($T^{p+1}$) is

$$\begin{aligned} T_{i,j}^{p} &= \frac{\alpha\,\Delta t\ \Delta r_{i-1,j}}{V_{i,j}\,\Delta r_{i-1,j}}\,T_{i-1,j}^{p} + \frac{\alpha\,\Delta t\ \Delta r_{i,j}}{V_{i,j}\,\Delta r_{i,j}}\,T_{i+1,j}^{p} \\ &+ \frac{\alpha\,\Delta t\ \Delta y_{i,j}}{V_{i,j}\,\Delta y_{i,j}}\,T_{i,j+1}^{p} + \frac{\alpha\,\Delta t}{V_{i,j}\left(\frac{K}{h_F\,\Delta y_{i,j-1}} + \frac{\Delta y_{i,j-1}}{\Delta y_{i,j-1}}\right)}\,T_{\infty}^{p} \\ &+ \Bigg(1 - \frac{\alpha\,\Delta t\ \Delta r_{i-1,j}}{V_{i,j}\,\Delta r_{i-1,j}} - \frac{\alpha\,\Delta t\ \Delta r_{i,j}}{V_{i,j}\,\Delta r_{i,j}} \\ &- \frac{\alpha\,\Delta t\ \Delta y_{i,j}}{V_{i,j}\,\Delta y_{i,j}} - \frac{\alpha\,\Delta t}{V_{i,j}\left(\frac{K}{h_F\,\Delta y_{i,j-1}} + \frac{\Delta y_{i,j-1}}{\Delta y_{i,j-1}}\right)}\Bigg)\,T_{i,j}^{p} \end{aligned} \qquad (3\ 8)$$

and the maximum time step is

$$\Delta t_{i,j} \le \frac{V_{i,j}}{\alpha\left(\frac{\Delta r_{i-1,j}}{\Delta r_{i-1,j}} + \frac{\Delta r_{i,j}}{\Delta r_{i,j}} + \frac{1}{\frac{k}{h_F\,\Delta y_{i,j-1}} + \frac{\Delta y_{i,j}}{\Delta y_{i,j-1}}} + \frac{\Delta y_{i,j}}{\Delta y_{i,j}}\right)} \qquad (3\ 9)$$

Node Type 5

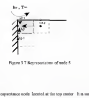


Figure 3 7 Representation of node 5

Specification

This node is a capacitance node located at the top center It is similar to node 3 except the left side is insulated (Figure 3 7) The equation for the nodal temperature at time step $T^{p+1}$ is

$$
\begin{aligned}
T_{ij}^{p+1} &= \frac{\alpha\,\Delta t\,\Delta r_{ij}}{V_{ij}\,\Delta r_{ij}}\,T_{i+1j}^{p} \\
&+ \frac{\alpha\,\Delta t}{V_{ij}\left(\frac{K}{h_T\,\Delta y_{ij+1}} + \frac{\Delta y_{ij}}{\Delta y_{ij}}\right)}\,T_\infty^{p} + \frac{\alpha\,\Delta t\,\Delta y_{ij}}{V_{ij}\,\Delta y_{ij-1}}\,T_{ij-1}^{p} \\
&+ \left(1 - \frac{\alpha\,\Delta t\,\Delta r_{ij}}{V_{ij}\,\Delta r_{ij}} - \frac{\alpha\,\Delta t}{V_{ij}\left(\frac{K}{h_T\,\Delta y_{ij+1}} + \frac{\Delta y_{ij}}{\Delta y_{ij}}\right)} - \frac{\alpha\,\Delta t\,\Delta y_{ij-1}}{V_{ij}\,\Delta y_{ij-1}}\right) T_{ij}^{p}
\end{aligned}
\tag{3 10}
$$

By setting the coefficient of $T^{p} > 0$, the nodal maximum time step becomes

$$\Delta t = \frac{V_{ij}}{\alpha \left( \frac{Ar_{ij}}{\Delta r_{ij}} + \frac{1}{\frac{K}{h_b\, Ay_{ij-1}} + \frac{\Delta y_{ij}}{Ay_{ij}}} + \frac{Ay_{ij-1}}{\Delta y_{ij}} \right)} \tag{3 11}$$

Node Type 6

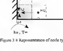


Figure 3 8 Representation of node type 6

Specification

This is similar to the node type 5 except it is at the bottom (Figure 3 8) The temperature at time step $T^{p+1}$ is

$$\begin{aligned} T_{ij}^{p+1} = {} & \frac{\alpha\, \Delta t\, Ar_{ij}}{V_{ij}\, \Delta r_{ij}} T_{i+1j}^{p} \\ & + \frac{\alpha\, \Delta t\, Ay_{ij}}{V_{ij}\, \Delta r_{ij}} T_{ij+1}^{p} + \frac{\alpha\, \Delta t}{V_{ij} \left( \frac{K}{h_b\, Ay_{ij}} + \frac{\Delta y_{ij-1}}{Ay_{ij-1}} \right)} T_{\infty}^{p} \\ & + \left(1 - \frac{\alpha\, \Delta t\, Ar_{ij}}{V_{ij}\, \Delta r_{ij}} - \frac{\alpha\, \Delta t\, Ay_{ij}}{V_{ij}\, \Delta y_{ij}} - \frac{\alpha\, \Delta t}{V_{ij} \left( \frac{K}{h_b\, Ay_{ij-1}} + \frac{\Delta y_{ij-1}}{Ay_{ij-1}} \right)} \right) T_{ij}^{p} \end{aligned} \tag{3 12}$$

and the nodal maximum time step is

$$\Delta t \leq \frac{1}{\alpha \left( \frac{\Delta r_{ij}}{\Delta r_i} + \frac{\Delta y_{ij}}{\Delta y_j} + \frac{1}{\frac{K}{h_s \Delta y_{j+1}} + \frac{\Delta y_{ij}}{\Delta y_{ij}}} \right)} \qquad (3\ 13)$$

Node Type 7

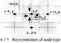


Figure 3 9 Representation of node type 7

Specification

This is a capacitance node surrounded by four capacitance nodes (Figure 3 9) A transient energy balance on the node (i,j) which is the sum of the heat conducted from the 4 adjacent nodes is equal to the increase in the internal energy of the node. By solving for the nodal temperature for time step ( $T^p$ )

$$\begin{aligned} T_{ij}^{p+1} = {} & \frac{\alpha \Delta t A r_{i+1,j}}{V_{ij} \Delta r_{i+1,j}} T_{i+1,j}^{p} + \frac{\alpha \Delta t A r_{ij}}{V_{ij} \Delta r_{ij}} T_{i-1,j}^{p} \\ & \frac{\alpha \Delta t A y_{ij}}{V_{ij} \Delta y_{ij}} T_{ij}^{p} \quad \frac{\alpha \Delta t A y_{ij+1}}{V_{ij} \Delta y_{ij+1}} T_{i,j+1}^{p} \\ & (1 \quad \frac{\alpha \Delta t A r_{i+1,j}}{V_{ij} \Delta r_{i+1,j}} \quad \frac{\alpha \Delta t A r_{ij}}{V_{ij} \Delta r_{ij}} \quad \frac{\alpha \Delta t A y_{ij}}{V_{ij} \Delta y_{j}} \quad \frac{\alpha \Delta t A y_{j+1}}{V_{ij} \Delta y_{ij+1}}) T_{ij} \end{aligned} \qquad (3\ 14)$$

By setting the coefficient of the last term $(T^{p})$ greater than 0 the maximum time step becomes

$$\Delta t_{ij} \le \frac{V_{ij}}{\alpha\left(\frac{Ar_{i-1,j}}{\Delta r_{i-1,j}} + \frac{Ar_{ij}}{\Delta r_{ij}} + \frac{Ay_{ij}}{\Delta y_{j}} + \frac{Ay_{ij+1}}{\Delta y_{ij}}\right)} \qquad (3\ 15)$$

Node Type 8

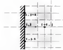


Figure 3 10 Representation of node type 8

Specification

This is a capacitance node located at the center and its left side is insulated It is surrounded by three capacitance nodes(Figure 3 10) The energy balance on the node (i,j) is the sum of the heat conducted from the 3 adjacent nodes is equal to its internal energy increase The equation for the nodal temperature at time step $(T^{p+1})$ is

$$\frac{\alpha\,\Delta t\,Ar_{i,j}}{V_{i,j}\,\Delta r_{i,j}}\,T_{i-1,j}^{p} + \frac{\alpha\,\Delta t\,Ay_{i,j}}{V_{i,j}\,\Delta y_{i,j}}\,T_{i,j+1}^{p} + \frac{\alpha\,\Delta t\,Ay_{i,j-1}}{V_{i,j}\,\Delta y_{i,j-1}}\,T_{i,j-1}^{p} + (1 - \frac{\alpha\,\Delta t\,Ar_{i,j}}{V_{i,j}\,\Delta r_{i,j}} - \frac{\alpha\,\Delta t\,Ay_{i,j}}{V_{i,j}\,\Delta y_{i,j}} - \frac{\alpha\,\Delta t\,Ay_{i,j-1}}{V_{i,j}\,\Delta y_{i,j-1}})\,T_{i,j}^{p} \quad (3.16)$$

By setting coefficient of $T_{i,j}^{p} \geq 0$, the nodal maximum time step of this node is

$$\Delta t_{i,j} \leq \frac{V_{i,j}}{\alpha\left(\frac{Ar_{i,j}}{\Delta r_{i,j}} + \frac{Ay_{i,j}}{\Delta y_{i,j}} + \frac{Ay_{i,j-1}}{\Delta y_{i,j-1}}\right)} \quad (3.17)$$

Node Type 9

Figure 3.11 Representation of node type 9

Specification

This is a capacitance surface node having a triangular cross-section ring shape, with volume $V_{triang\,i,j}$ (Figure 3.11). Heat convects from the right boundary into the node through the sloped surface area ($Ar_{slope\,i,j}$) and conducts from two capacitance nodes on the left and top into the node through the average cross section areas $Ar_{avg\,i-1,j}$ and $Ay_{avg\,i,j}$ (see derivation in appendix A)

The energy balance equation is

$$\rho\ Cp\ V_{wing\ i,j}\frac{(T_{i,j}^{P+1}-T_{i,j}^{P})}{\Delta t}=\frac{K\ Ar_{avg\ i-1,j}}{\Delta r_{i-1,j}}(T_{i-1,j}^{P}-T_{i,j}^{P})$$
$$-h_{g}\ Ar_{slope\ i,j}(T_{\infty}^{P}-T_{i,j}^{P})+\frac{K\ Ay_{avg\ i,j}}{\Delta y_{i,j}}(T_{i,j+1}^{P}-T_{i,j}^{P}) \tag{3.18}$$

The nodal temperature for time step ( $T^{P+1}$ ) becomes

$$T_{i,j}^{P+1}=\frac{\alpha\ \Delta t\ Ar_{avg\ i-1,j}}{V_{wing\ i,j}\ \Delta r_{i-1,j}}T_{i-1,j}^{P}-\frac{\alpha\ h_{g}\ \Delta t\ Ar_{slope\ i,j}}{K\ V_{wing\ i,j}}T_{\infty}^{P}-\frac{\alpha\ \Delta t\ Ay_{avg\ i,j}}{V_{wing\ i,j}\ \Delta y_{i,j}}T_{i,j+1}^{P}$$
$$+(1-\frac{\alpha\ \Delta t\ Ar_{avg\ i-1,j}}{V_{wing\ i,j}\ \Delta r_{i-1,j}}-\frac{\alpha\ h_{g}\ \Delta t\ Ar_{slope\ i,j}}{K\ V_{wing\ i,j}}-\frac{\alpha\ \Delta t\ Ay_{avg\ i,j}}{V_{wing\ i,j}\ \Delta y_{i,j}})T_{i,j}^{P} \tag{3.19}$$

and the maximum time step for the node is

$$\Delta t_{i,j}\le\frac{V_{wing\ i,j}}{\alpha\ (\frac{h_{g}\ Ar_{slope\ i,j}}{K}+\frac{Ar_{avg\ i-1,j}}{\Delta r_{i-1,j}}+\frac{Ay_{avg\ i,j}}{\Delta y_{i,j}})} \tag{3.20}$$

Node Type 10

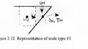


Figure 3 12 Representation of node type 10

Specification

This is a capacitance surface node having a shape of a triangle ring and the nodal volume is $V_{triang\ i,j}$. It is located at the right top corner (Figure 3 12). Heat convects from the right side into the node through the sloped area $Ar_{slope\ i,j}$ and conducts from the left node through the average cross section area. Node on the top is a NCSN with convective boundary. The energy balance of this node becomes

$$\rho\ Cp\ V_{triang\ i,j} \frac{(T_{i,j}^{p} - T_{i,j}^{p})}{\Delta t} = \frac{K\ Ar_{avg\ i-1,j}}{\Delta r_{i-1,j}} (T_{i-1,j}^{p} - T_{i,j}^{p}) + h_R\ Ar_{slope\ i,j} (T_{\infty}^{p} - T_{i,j}^{p}) + \frac{1}{\frac{1}{h_T\ Ay_{i,j+1}} + \frac{\Delta y_{i,j}}{K\ Ay_{avg\ i,j}}} (T_{\infty}^{p} - T_{i,j}^{p}) \tag{3 21}$$

and the equation for the nodal temperature for time step ($T^{p+1}$) is

$$T_{i}^{p+1} = \frac{\alpha\,\Delta t\,Ar_{avg\,i-1,j}}{V_{wing\,i,j}\,\Delta r_{i-1,j}}\,T_{i-1,j}^{p} + \frac{\alpha\,h_{E}\,\Delta t\,Ar_{elips\,i,j}}{K\,V_{wing\,i,j}}\,T_{\infty}^{p} + \frac{\alpha\,\Delta t}{V_{wing\,i,j}\left(\frac{K}{h_{T}\,\Delta y_{i,j+1}} + \frac{\Delta y_{i,j}}{\Delta y_{avg\,i,j}}\right)}\,T_{\infty}^{p} + \left(1 - \frac{\alpha\,\Delta t\,Ar_{avg\,i-1,j}}{V_{wing\,i,j}\,\Delta r_{i-1,j}} - \frac{\alpha\,h_{E}\,\Delta t\,Ar_{elips\,i,j}}{K\,V_{wing\,i,j}} - \frac{\alpha\,\Delta t}{V_{wing\,i,j}\left(\frac{K}{h_{T}\,\Delta y_{i,j+1}} + \frac{\Delta y_{i,j}}{\Delta y_{avg\,i,j}}\right)}\right)T_{i,j}^{p} \tag{3.22}$$

By setting coefficient of $T_{i,j}^{p} \geq 0$, the nodal maximum time step of this node is

$$\Delta t_{i,j} \leq \frac{V_{wing\,i,j}}{\alpha\left(\frac{Ar_{avg\,i-1,j}}{\Delta r_{i-1,j}} + \frac{h_{E}\,Ar_{elips\,i,j}}{K} + \frac{1}{\frac{K}{h_{T}\,\Delta y_{i,j+1}} + \frac{\Delta y_{i,j}}{\Delta y_{avg\,i,j}}}\right)} \tag{3.23}$$

Grid Generation in a Finite Elliptical Cylinder

The equation of an ellipse is given by

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \tag{3.24}$$

where '2a' is the length of the major axis, '2b' is the length of the minor axis. A two dimensional finite difference model is developed for a finite elliptical cylinder with height

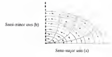
H Because of the symmetry of the finite elliptical cylinder only the right half is used to develop the equations Heat flows into the finite elliptical cylinder from two directions along the curve line drawn perpendicularly from the node on the ellipse perimeter toward the center (Pham 1991, Erdogdu 1996) and along the height The equation of the curve line is given as

$$y = c\ x^{n} \tag{3 25}$$

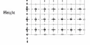
Figure 3 13 shows the generation of nodal network within a finite elliptical cylinder The expressions of distances between nodes, areas of heat transfer and nodal volumes are presented in the Appendix B More detail in grid generation of an infinite elliptical cylinder could be obtained from Erdogdu(1996)

Energy Balance Equations

From the side view of grid generation in a finite elliptical cylinder (Figure 3 13 b) twelve different types of nodes were generated within the finite elliptical cylinder as shown in Figure 3 14 The derivation of the energy balance equations and the calculated maximum time steps for the volume elements were types 1 to 8 of the finite elliptical model are the same as those for the cone frustum model. The following are the developed equations for the nodes types 9 to 12 of the finite elliptical cylinder



a. Top view



b Side view

Fig 3 13 Grid Generation in a finite elliptical cylinder

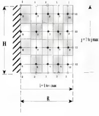


Figure 3 14 Volume element definitions in a finite elliptical cylinder

● Capacitance nodes
Non- Capacitance Surface Nodes

Node Type 9 (Finite Elliptical Cylinder)

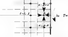


Figure 3 15 Representation of node type 9(Finite elliptical cylinder)

Specification

This is a capacitance node having a NCSN with convective boundary on the right side(Figure 3 15) The temperature in time step $(T^{p+1})$ is

$$\begin{aligned}T_{i,j}^{p+1} = {} & \frac{\alpha\,\Delta t\ Ar_{i-1/2,j}}{V_{i,j}\,\Delta r_{i-1/2,j}} T_{i-1,j}^{p} + \frac{\alpha\,\Delta t}{V_{i,j}\left(\frac{K}{h_\infty Ar_{i+1/2,j}} + \frac{\Delta r_{i,j}}{Ar_{i,j}}\right)} T_\infty^{p} \\ & + \frac{\alpha\,\Delta t\ Ay_{i,j}}{V_{i,j}\,\Delta y_{i,j}} T_{i,j+1}^{p} + \frac{\alpha\,\Delta t\ Ay_{i,j}}{V_{i,j}\,\Delta y_{i,j}} T_{i,j-1}^{p} \\ & + \left(1 - \frac{\alpha\,\Delta t\ Ar_{i-1/2,j}}{V_{i,j}\,\Delta r_{i-1/2,j}} - \frac{\alpha\,\Delta t}{V_{i,j}\left(\frac{K}{h_\infty Ar_{i+1/2,j}} + \frac{\Delta r_{i,j}}{Ar_{i,j}}\right)}\right. \\ & \left. - \frac{\alpha\,\Delta t\ Ay_{i,j}}{V_{i,j}\,\Delta y_{i,j}} - \frac{\alpha\,\Delta t\ Ay_{i,j+1}}{V_{i,j}\,\Delta y_{i,j}}\right) T_{i,j}^{p}\end{aligned} \tag{3 26}$$

By setting coefficient of $T_{i,j}^{p} \ge 0$ the maximum time step of this node is

$$dt_{ij} \le \frac{1}{\alpha\left(\frac{\Delta r_{ij}}{dr_{ij}} \quad \frac{1}{\frac{k}{h_R \Delta r_{i+1,j}} + \frac{dr_{ij}}{\Delta r_{ij}}} \quad \frac{\Delta y_{ij}}{dy_{ij}} + \frac{h}{dy_{ij}}\right)} \tag{3.27}$$

Node Type 10 (Finite Elliptical Cylinder)

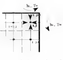


Figure 3-16 Representation of node type 10 (Finite elliptical cylinder)

Specification

This is a capacitance node having a NCSN with convective boundary on its top and right sides(Figure 3.16). The temperature in time step ( $T^{p+1}$ ) is

$$\begin{aligned} T_{ij}^{p} \quad & \frac{\alpha t \, \Delta r_{i+1,j}}{V_{ij} \, \Delta r_{ij}} \quad \frac{\alpha \Delta t}{V_{ij}\left(\frac{k}{h_R \Delta r_{ij}} \quad \frac{\Delta r_{ij}}{\Delta r_{ij}}\right)} T^{p} \\ & \frac{\alpha \Delta t}{V_{ij}\left(\frac{k}{h_T \Delta y_{ij-1}} \quad \frac{\Delta y_{ij}}{\Delta y_{ij}}\right)} T_{\infty}^{p} \quad \frac{\alpha \Delta t \, \Delta y_{ij-1}}{V_{ij} \, \Delta y_{ij-1}} T_{ij-1}^{p} \\ & (1 \quad \frac{\alpha \Delta t \, \Delta r_{ij}}{V_{ij} \, \Delta r_{ij}} \quad \frac{\alpha \Delta t}{V_{ij}\left(\frac{K}{h_R \Delta r_{i,j}} \quad \frac{\Delta r_{ij}}{\Delta r_{ij}}\right)} \\ & \frac{\alpha \Delta t}{V_{ij}\left(\frac{k}{h_T \Delta y_{ij-1}} + \frac{\Delta y_{ij}}{\Delta y_{ij}}\right)} \quad \frac{\alpha \Delta t \, \Delta y_{ij}}{V_{ij} \, \Delta y_{ij-1}} ) T_{ij}^{p} \end{aligned} \tag{3.28}$$

By setting coefficient of $T^{t} \geq 0$, the maximum time step of this node is

$$\Delta t_{ij} \leq \frac{V_{ij}}{\alpha\left(\frac{\Delta r_{i,j}}{\Delta r_{i-1,j}} + \frac{1}{\frac{K}{h_x \Delta r_{i,j}} + \frac{\Delta r_{ij}}{\Delta r_{ij}}} + \frac{1}{\frac{K}{h_y \Delta y_{ij+1}} + \frac{\Delta y_{ij}}{\Delta y_{ij}}} + \frac{\Delta y_{ij-1}}{\Delta y_{ij}}\right)} \qquad (3.29)$$

Node Type 11 (Finite Elliptical Cylinder)

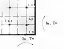


Figure 3 17 Representation of node type 11(Finite elliptical cylinder)

Specification

This is a capacitance node, having NCSN nodes with convection boundary on its right and bottom (Figure 3 17) The temperature in time step ($T^{t+1}$) is

$$
\begin{aligned}
T_{i,j}^{p+1} = {} & \frac{\alpha\Delta t\,\Delta r_{i-1,j}}{V_{i,j}\Delta r_{i,j}}T_{i-1,j}^{p} + \frac{\alpha\Delta t}{V_{i,j}\left(\frac{K}{h_B\Delta r_{i,j}}+\frac{\Delta r_{i,j}}{\Delta r_{i,j}}\right)}T_{\infty} \\
& + \frac{\alpha\Delta t\,\Delta y_{i,j}}{V_{i,j}\Delta y_{i,j}}T_{i,j}^{p} + \frac{\alpha\Delta t}{V_{i,j}\left(\frac{K}{h_B\Delta y_{i,j+1}}+\frac{\Delta y_{i,j+1}}{\Delta y_{i,j}}\right)}T_{\infty} \\
& + \Bigg(1 - \frac{\alpha\Delta t\,\Delta r_{i-1,j}}{V_{i,j}\Delta r_{i,j}} - \frac{\alpha\Delta t}{V_{i,j}\left(\frac{K}{h_B\Delta r_{i,j}}+\frac{\Delta r_{i,j}}{\Delta r_{i,j}}\right)} \\
& - \frac{\alpha\Delta t\,\Delta y_{i,j}}{V_{i,j}\Delta y_{i,j}} - \frac{\alpha\Delta t}{V_{i,j}\left(\frac{K}{h_B\Delta y_{i,j}}+\frac{\Delta y_{i,j+1}}{\Delta y_{i,j+1}}\right)}\Bigg)T_{i,j}^{p}
\end{aligned}
\qquad (3.30)
$$

By setting coefficient of $T_{i,j}^{p} \geq 0$, the nodal maximum time step yields

$$
\Delta t \leq \frac{V_{i,j}}{\alpha\left(\frac{\Delta r_{i-1,j}}{\Delta r_{i,j}} + \frac{1}{\frac{K}{h_B\Delta r_{i,j}}+\frac{\Delta r_{i,j}}{\Delta r_{i,j}}} + \frac{\Delta y_{i,j}}{\Delta y_{i,j}} + \frac{1}{\frac{K}{h_B\Delta y_{i,j+1}}+\frac{\Delta y_{i,j}}{\Delta y_{i,j+1}}}\right)} \qquad (3.31)
$$

Node Type 12 (Finite Elliptical Cylinder)

Figure 3.18 Representation of node type 12 (Finite elliptical cylinder)

### Specification

This is a NCSN located on the right surface(Figure 3 18) Its temperature can be written as

$$T_{i,j}^{p} = \frac{k\,Ar_{i-1,j}\,T_{i-1,j}^{p} + h_R\,Ar_{i,j}\,\Delta e_{i,j}\,T_{\infty}^{p}}{k\,Ar_{i-1,j} + h_R\,Ar_{i,j}\,\Delta e_{i,j}} \qquad (3\ 32)$$

## Validation of the Developed Models

### Mathematical Validation of the Models Using Existing Cylindrical Model

The 2-dimensional finite difference model for a finite cylinder developed by the energy balance approach with non-capacitance surface nodes, was used to validate the cone and finite elliptical cylinder models mentioned above The accuracy of the cylinder model was validated by comparing its results with those of analytical solutions and experimental temperature measurements (Erdogdu, 1996) Details of the development of the cylindrical model are given by Welt et al (1997)

Both the cone and finite elliptical cylinder models were assigned the same dimensions as the cylinder except that the large radius of the cone could not be set smaller or equal to the small radius Therefore the large radius used in the cone model was set slightly bigger than the small radius (Table 3 1) Grids and nodes in the cylinder cone and finite elliptical cylinder models were generated so that the temperatures at the same locations could be compared.

The identical values of thermal diffusivity ($1.4\times10^{-7}$ $m^2/s$), initial temperature (22 °C), heating temperature (121 °C), surface heat transfer coefficient during heating (2000 $W/m^2$ K), heating time (60 min), cooling temperature (20 °C), surface heat transfer coefficient during cooling (300 $W/m^2$ K) and cooling time (60 min) were used as inputs to the three models.

The center temperature histories and temperature distributions at different locations simulated using the cone and the finite elliptical cylinder model were compared with the simulations at the same points obtained by the validated cylinder model.

Experimental Validation with Acrylic Materials

Acrylic finite elliptical cylinders and cones of different dimensions were used in the heat penetration tests in order to validate the conduction heat transfer models developed. The acrylic rod with a diameter of 10.24 cm (Acutech Plastics, Reading, PA) was formed in to different shapes and sizes. The thermophysical properties are given in Table 3.2. The dimensions of the cones are shown in Table 3.3 and those of the finite elliptical cylinders are shown in Table 3.4. The acrylic elliptical cylinder # 1 was used in the work of Erdogdu (1996) and the acrylic elliptical cylinder # 2 was used in the work of Kim and Teixeira (1996).

It was important to choose the locations where the temperatures were measured. Ideally the location of the thermocouple tip should be exactly at the location of the numerical model node in order to avoid interpolation. After the thermocouple positions

Table 3.1 Dimensions of the cylinder, cone and finite elliptical cylinder used in the mathematical validation

| model | dimension | distance (cm.) |
|---|---|---|
| Cylinder | Radius | 4.35 |
| | Height | 11.59 |
| Cone | Big Radius ( R ) | 4.45 |
| | Small Radius ( r ) | 4.35 |
| | Height | 11.59 |
| Finite elliptical cylinder | a | 4.35 |
| | b | 4.35 |
| | Height | 11.59 |

Table 3.2 Thermophysical properties of the acrylic rod used in the experimental validation

| Properties | Value |
|---|---|
| Thermal Conductivity (W/m-K) | 0.166-0.25 |
| Specific Heat (J/kg-K) | 1464.40 |
| Density (kg/m$^3$) | 1170-1200 |

** Source: Acutech Plastics, Reading, PA.

Table 3.3 Dimensions of the acrylic cones and locations of the thermocouple tips used in the experimental validation

| Shape | Thermocouple # | x* (cm.) | y* (cm.) |
|---|---|---|---|
| Cone#1 | 1 | 1.59 | 7.62 |
| Big Radius = 5.08 cm | 2 | 0.00 | 6.35 |
| Small Radius = 0 cm | 3 | 1.27 | 6.35 |
| Height = 12.7cm | 4 | 2.54 | 7.62 |
| Cone#2 | 1 | 1.43 | 2.70 |
| Big Radius = 5.08 cm. | 2 | 0.64 | 5.56 |
| Small Radius = 2.54 cm | 3 | 2.06 | 4.92 |
| Height = 7.62 cm. | | | |
| Cone # 3 | 1 | 1.91 | 7.46 |
| Big Radius = 3.81 cm | 2 | 0.00 | 7.46 |
| Small Radius = 1.27 cm | 3 | 0.80 | 6.83 |
| Height = 12.7 cm. | | | |

x is the distance from the axis of symmetry of the cone to the location of the thermocouple
y is the distance from the bottom of the cone to the location of the thermocouple

Table 3.4 Dimensions of the acrylic finite elliptical cylinder and locations of the thermocouple tips used in the experimental validation

| Shape | Thermocouple # | x* (cm.) | y* (cm.) | z* (cm.) |
|---|---|---|---|---|
| Finite elliptical cylinder #1 | 1 | 0.00 | 0.00 | 0.00 |
| Semi major axis (a) = 2.22 cm | 2 | 1.22 | 0.00 | 0.30 |
| Semi minor axis (b) = 1.72 cm | | | | |
| Height = 15.20 cm | | | | |
| Finite elliptical cylinder #2 | 1 | 2.22 | 2.22 | 0.64 |
| Semi major axis(a) = 4.65 cm. | 2 | 1.59 | 1.59 | 0.64 |
| Semi minor axis = 3.13 cm. | 3 | 0.00 | 0.00 | 0.00 |
| Height = 2.54 cm. | 4 | 1.59 | 1.59 | 0.32 |

x is the distance( in cross section) from the center in x direction to the thermocouple
y is the distance (in cross section)from the center in y direction to the thermocouple
Z is the height distance from the center to the thermocouple

were assigned. Small holes were drilled to insert insulated 36-gage thermocouples at those positions. The thermocouples were set using epoxy glue and sealed at the surface with silicone.

The computerized data acquisition system, Can-Calc program® developed by Dr. M.O. Balaban of the University of Florida was used to read temperatures. Thermocouples were connected to the DAS-TC A/D board from MetraByte (Cleveland, OH). All thermocouples were calibrated with a mercury-in-glass thermometer prior to each experiment. In order to obtain uniform initial internal temperatures, the acrylic shapes were immersed in a well agitated constant temperature water container for at least 12 hours. The temperatures at every thermocouple location within the shapes and the water temperature were recorded until the difference was within 0.5°C.

Heat penetration tests were carried out in a temperature controlled water bath with adjustable water agitator set at the highest speed (Fischer Scientific, Pittsburgh, PA). Once a constant water temperature was reached, the shape was promptly transferred into the water bath. The water temperature and temperatures within the acrylic model were recorded every 10 seconds. In experiments where variable water temperature was needed, ice water was used to adjust the water temperature. Both constant and variable water temperature experiments were conducted.

The water temperatures used in the simulations were the actual temperatures recorded during the heat penetration tests. For each shape, optimum number of nodes was found by repeating calculations with increasing the number of nodes until changes in the calculated temperatures were negligible The predicted temperature histories at every thermocouple location were compared with experimental values

Calculation for Retention of Quality Factors

The calculation for retention of any quality factors makes use of the temperature predicted at every volume element after each iterations during the numerical solution of the conduction heat transfer equations. Since the D value of a quality factors changes as a function of temperature and Z value, it was updated for every volume element as

$$D_T = D_{ref}\, 10^{\frac{(T_{ref} - T_{element})}{Z}} \tag{3 33}$$

Using the updated D value ($D_T$), the retention after a time change of Δt could be calculated as

$$N_{(t \Delta t)} = N_t\, 10^{(\Delta t / D_T)} \tag{3 34}$$

An initial retention of 100% was used and the percent volume average retention after every time interval was calculated by volume-averaging the retention throughout the container

Calculation of Sterilizing Value ($F_o$)

The $F_o$ is the integrated lethality calculated by the general method which is based on the actual temperature at the cold point for the entire process

$$F_0 = \int_0^t 10^{\frac{T-121.1}{Z}} dt \tag{3.35}$$

where T is temperature at the cold point at time t, and the Z value was assumed to be 10°C

The position of cold point for the finite elliptical cylinder and cylinders are at the geometrical center. In a cone frustum the position of the cold point depends on the shape and size. Therefore, it is necessary to search for a cold point position and calculate its $F_0$. The cold point was searched for by comparing temperatures of nodes along the center line in the axial direction. A fine grid was required to obtain an accurate cold point position.

## Optimization of Quality Retention

The objective function was the volume average quality retention, expressed as

$$(\frac{N}{N_o})_{avg} = \frac{1}{V}\int_0^V 10^{-\frac{1}{D_{ref}}\int_0^t 10^{\frac{T-T_{ref}}{z}} dt} dV \tag{3.36}$$

The constraint of the optimization procedure was a target $F_o$ value at the cold point including both heating and cooling period ($t_h + t_c$)

$$F_0 = \int_{0}^{t_h} 10^{\frac{T-T_{ref}}{Z}} dt + \int_{t_h}^{t_c} 10^{\frac{T-T_{ref}}{Z}} dt \qquad (3.37)$$

A $F_o$ value of 3 minutes was used. Although this value is less than those generally used in the industry, it shortened that calculation times in this study.

Quality factors with different combinations of D and Z values were used in this study. Influential variables including thermal diffusivity of food product, surface heat transfer coefficient, as well as shapes and sizes of the cones and finite elliptical cylinder were used in the investigation to study their effect on those factors. The values chosen for these variable are summarized in Table 3.5.

The food products with uniform initial temperature of 22 °C were assumed to be processed at different constant retort temperatures ranging from 110 to 140 °C at 2 °C intervals. After heating at the specified temperature, the food was then cooled at a constant cooling temperature of 20 °C until the center temperature was less than or equal to 50 °C.

The contribution of $F_o$ during cooling should not be neglected for a conduction heating product. Depending on the cold point temperature at the start of cooling, size of the container and other factors in a conduction heating situation, the contribution of cooling to $F_o$ could be as much as 40% of the total (Datta et al.,1986). In this study the computer program developed for simulation of quality retention can determine the exact

Table 3.5 Variables used in the quality retention studies

| Variable | Number of levels | Values |
|---|---|---|
| **Kinetics of quality factors** | | |
| $D_{121.1^{\circ}C}$ (min) | 6 | 40,80,120,160,200 |
| Z (°C) | 6 | 10, 20, 30, 40, 50, 60 |
| **Processing Conditions** | | |
| Heating Temperature (°C) | 11 | 110-140, at 2°C intervals |
| Heat transfer coef (W/m$^2$ °C) | 2 | 300 and 2000 w/ m$^2$ K |
| **Containers** | | |
| Cone | 3 | (see dimensions in Table 3.6) |
| Finite Elliptical cylinder | 2 | (see dimensions in Table 3.7) |
| **Thermal Properties of food** | | |
| Thermal diffusivity ($\times 10^{-7}$ m$^2$/s) | 3 | 1.2 1.4,1.6 |

Table 3.6 Dimension of the cones used in the quality retention studies

| Dimension | Cone # 1 | Cone #2 | Cone #3 |
|---|---|---|---|
| Big Radius (cm.) | 4.50 | 6.20 | 4.00 |
| Small Radius(cm.) | 2.75 | 5.00 | 2.00 |
| Height(cm.) | 8.00 | 3.40 | 11.50 |
| Volume (cm$^3$) | 336.60 | 336.60 | 337.20 |
| Surface area (cm$^2$) | 273.90 | 326.30 | 282.80 |
| Volume / Surface | 1.23 | 1.03 | 1.19 |

Table 3.7 Dimension of the finite elliptical cylinder used in the quality retention studies

| Dimension | Finite elliptical cylinder #1 | Finite elliptical cylinder #2 |
|---|---|---|
| Semi Major Axis, a (cm.) | 8.10 | 7.46 |
| Semi Minor Axis b (cm.) | 5.32 | 4.45 |
| Height(cm.) | 3.81 | 2.96 |
| Volume (cm$^3$) | 515.37 | 308.71 |
| Surface area (cm$^2$) | 432.82 | 321.01 |
| Volume / Surface | 1.19 | 0.96 |

heating and cooling times at the given heating temperature to obtain the specified $F_o$ value and calculate nutrient retention at the end of that process.

The exact time to stop heating and start cooling in order to obtain the desired $F_o$ value was found as follows. At the end of a given time step during heating, the $F_o$ for heating was calculated, then cooling was simulated until the cold point reached 50 °C, and the contribution of cooling to $F_o$ was calculated. If the total $F_o$ (heating + cooling) was less than the desired $F_o$, heating could still proceed. Otherwise, a bisection method was used within the last time step to find the exact time such that the total $F_o$ would not be larger than 0.0001 min compared to the desired $F_o$.

The percent quality retention for each processing condition was plotted against processing temperatures. The optimum temperature giving the maximum quality retention was located by a spline interpolation.

# CHAPTER 4
# RESULT AND DISCUSSION

## Heat Transfer Model Validation

### Mathematical Validation of the Cone model with Existing Cylindrical Model

The center temperature histories of a cylinder predicted by the cone model and cylinder model were compared, and are shown in Figure 4.1. The agreement was well within a variation of 0.6 °C for the entire process. Because of the limitation of the cone model, the big radius used in the cone model was slightly bigger than the radius of the cylinder used in the cylinder model. This difference in dimensions caused the center temperature predicted using the cone model to be slightly lower during heating and higher during cooling compared to that predicted by the cylinder model.

After heating and cooling, the temperature distributions of the right bottom quarter of the cylinder obtained from the cone model and the cylinder model were compared in Table 4.1. The results show very good agreement of temperatures for all locations with variations within 0.6 °C for all locations indicated that the cone model could predict temperature distribution of a cylinder-like object as accurately as the validated cylinder model.

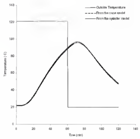


Figure 4.1 Comparison of center temperature of 307*409 can predicted using the cone model and cylinder model

Table 4.1 Comparison of predicted temperature (°C) distribution within 307 * 409 can after heating and cooling using the cone model and the cylinder model

| Distance from the center point Y (cm.) | | x(cm.) | | | | |
|---|---|---|---|---|---|---|
| | | 0 | 0.79 | 1.59 | 2.38 | 3.17 |
| Cone | 0 | 47.5 | 46.26 | 42.7 | 37.27 | 30.7 |
| Cylinder | | 46.99 | 45.76 | 42.19 | 36.77 | 30.23 |
| Cone | 1.66 | 45.3 | 44.18 | 42.19 | 35.86 | 29.79 |
| Cylinder | | 44.96 | 43.81 | 40.51 | 35.51 | 29.46 |
| Cone | 4.97 | 38.59 | 37.74 | 35.31 | 31.62 | 27.14 |
| Cylinder | | 38.37 | 37.53 | 35.1 | 31.41 | 29.46 |
| Cone | 4.97 | 27.13 | 26.8 | 25.87 | 24.45 | 22.73 |
| Cylinder | | 27.06 | 26.73 | 20.2 | 24.38 | 22.67 |
| Cone | 5.79 | 27.13 | 20.23 | 20.2 | 20.15 | 20.09 |
| Cylinder | | 20.24 | 20.26 | 20.2 | 20.15 | 20.06 |

However, using the cone model for predicting temperature of a cone which has a shape close to a cylinder is not recommended. In the grid generation of the cone model nodes in the cone height were automatically set equally to the difference between nodes in a big radius and a small radius. If this difference is very small, the elements in the sloped area become very small. Since the forward difference explicit procedure was used for the finite difference approximations, the maximum time step became smaller when the grid size is decreased resulting in longer computer calculation times.

### Mathematical Validation of the Finite Elliptical Cylinder Model with Existing Cylindrical Model

To determine the accuracy of the developed model, the center temperature histories of a cylinder (Eccentricity = 0) predicted by the finite elliptical cylinder model were compared with that obtained from the validated cylinder model for the same conditions of size, thermal diffusivities, initial temperatures, outside temperatures and surface heat transfer coefficients. The predicted temperatures from the two models were identical throughout the heating and cooling periods (Figure 4.2).

The final temperature distributions obtained from the two models were also identical (Table 4.2). This validation illustrated that there was no difference in the temperature prediction for a finite cylinder using the finite elliptical cylinder model and the cylinder model. However, at the same accuracy, the finite elliptical cylinder model was slower since the elements created in the finite elliptical cylinder model were smaller than those in the cylinder model.

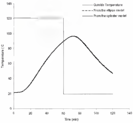


Figure 4.2 Comparison of center temperature of 307*409 can predicted using the finite elliptical cylinder model and the cylinder model

Table 4 2 Comparison of temperature (°C) distribution within 307 * 409 can after heating and cooling using the finite elliptical cylinder model and the cylinder model

| | Distance from the center point Y (cm) | x(cm) | | | | |
|---|---|---|---|---|---|---|
| | | 0 | 0 79 | 1 59 | 2 38 | 3 17 |
| Ellipse | 0 | 46 99 | 45 76 | 42 19 | 36 77 | 30.23 |
| Cylinder | | 46 99 | 45 76 | 42 19 | 36 77 | 30 23 |
| Ellipse | 1 66 | 44 96 | 43 81 | 40 51 | 35 51 | 29 46 |
| Cylinder | | 44 96 | 43 81 | 40 51 | 35 51 | 29 46 |
| Ellipse | 3 31 | 38 37 | 37 53 | 35 1 | 31 41 | 26 96 |
| Cylinder | | 38 37 | 37 53 | 35 1 | 31 41 | 26 96 |
| Ellipse | 4 97 | 27 06 | 26 73 | 25 8 | 24 38 | 22 67 |
| Cylinder | | 27 06 | 26 73 | 25 8 | 24 38 | 22 67 |
| Ellipse | 5 79 | 27 06 | 20 23 | 20 2 | 20 15 | 26 96 |
| Cylinder | | 20 24 | 20 23 | 25 8 | 20 15 | 20 09 |

## Experimental Validation with Acrylic Materials

An acrylic material was used as a model for experimental validation of the developed heat transfer models because it is homogeneous, heats by conduction, has known thermal properties that could be obtained from the manufacturer and is easily to be shaped into different geometries. The experimental temperatures at the different locations within 2 finite elliptical cylinders and the 3 acrylic cones were compared with the simulation temperatures (Figures 4.3- 4.12). The corresponding heat transfer coefficients and thermal properties used in the experiments are included in those figures. The dimensions and the thermocouple locations are given in Table 3.3. The experimental data can be seen in Appendix C (Table C.1-C.10).

The experimental results agree well with the simulations for all locations of every geometrical shape in response to either constant or variable outside temperatures. The heat transfer coefficient was selected by a search procedure to obtain a minimum absolute difference between simulated and experimental temperatures for all thermocouple locations. In the search procedure, the values of thermal conductivity and diffusivity (1.9 W/m K and 1.09 $m^2$/sec respectively) values given by the manufacturer were used for all conically shaped acrylic model. Surface heat transfer coefficient values used to obtain good agreement between experiment and simulation for all points were within 75-150 W/ $m^2$ K. These values were in the same range of values reported by Lebowitz and Bhowmik (1989) who experimentally determined h value of 186 ± 54 W/ $m^2$ K for thermal processing of thin retortable pouches under 120° C pressurized-water with forced convection. In a study of heat transfer in a bowl which has a similar shape to a cone,

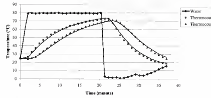


Figure 4.3 Comparison of measured and predicted temperatures at 2 locations within the finite elliptical cylinder # 1, Experiment I

(The continuous lines are temperatures predicted using $h = 1300$ W/ $m^2$ K, thermal conductivity = 0.195 W/m K and thermal diffusivity = $1.12 \times 10^{-7}$ $m^2/s$. Dimension and locations of thermocouple tips of the finite elliptical cylinder # I are shown in Table 3.4.)

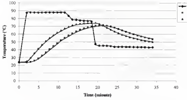


Figure 4.4 Comparison of measured and predicted temperatures at 2 locations within the finite elliptical cylinder # 1. Experiment II.

(The continuous lines are temperatures predicted using $h = 1200$ W/ $m^2$ K, thermal conductivity = 0.195 W/m K, and thermal diffusivity = $1.12 \times 10^{-7}$ $m^2$/s. Dimension and locations of thermocouple tips of the finite elliptical cylinder # 1 are shown in Table 3.4.)

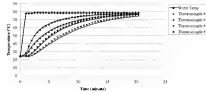


Figure 4.5 Comparison of measured and predicted temperatures at 4 locations within the finite elliptical cylinder # 2, Experiment I
(The continuous lines are temperatures predicted using h = 400 W/ $m^2$ K, thermal conductivity = 0.25 W/m K, and thermal diffusivity = 1.49 x $10^{-7}$ $m^2$/s. Dimension and locations of thermocouple tips of the finite elliptical cylinder # 2 are shown in Table 3.4.)

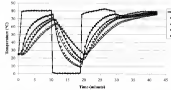


Figure 4.6 Comparison of measured and predicted temperatures at 4 locations within the finite elliptical cylinder # 2, Experiment II )

(The continuous lines are temperatures predicted using h = 400 W/ m$^2$ K, thermal conductivity = 0.26 W/m K, and thermal diffusivity = 1.49 x 10$^{-7}$ m$^2$/s Dimension and locations of thermocouple tips of the finite elliptical cylinder # 2 are shown in Table 3.4 )

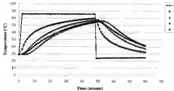


Figure 4.7 Comparison of measured and predicted temperatures at 4 locations within the cone # 1 Experiment I

(The continuous lines are temperatures predicted using h = 75 W/ $m^2$ K thermal conductivity = 0.19 W/m K, and thermal diffusivity = 1.09 x $10^{-7}$ $m^2/s$ Dimension and locations of thermocouple tips of the cone #1 are shown in Table 3.3 )

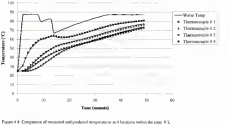


Figure 4 8 Comparison of measured and predicted temperatures at 4 locations within the cone # 1, Experiment II

(The continuous lines are temperatures predicted using h = 110 W/ $m^2$ K, thermal conductivity = 0 19 W/m K, and thermal diffusivity = 1 09 x $10^{-7}$ $m^2$/s Dimension and locations of thermocouple tips of the cone # 1 are shown in Table 3 3 )

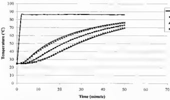


Figure 4.9 Comparison of measured and predicted temperatures at 3 locations within the cone # 2 Experiment I. (The continuous lines are temperatures predicted using h = 150 W/ m$^2$ K, thermal conductivity = 0.19 W/m K, and thermal diffusivity = 1.09 x 10$^{-7}$ m$^2$/s. Dimension and locations of thermocouple tips of the cone # 2 are shown in Table 3.3.)

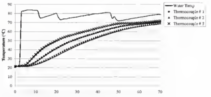


Figure 4 10 Comparison of measured and predicted temperatures at 3 locations within the cone # 2 Experiment II.

(The continuous lines are temperatures predicted using h = 120 W/ $m^2$ K, thermal conductivity = 0 19 W/m K, and thermal diffusivity = 1 09 x $10^{-7}$ $m^2$/s Dimension and locations of thermocouple tips of the cone # 2are shown in Table 3 3 )

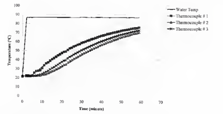


Figure 4.11 Comparison of measured and predicted temperatures at 3 locations within the cane # 3 Experiment I

(The continuous lines are temperatures predicted using h = 135 W/ $m^2$ K, thermal conductivity = 0.19 W/m K and thermal diffusivity = 1.09 x $10^{-7}$ $m^2$/s. Dimension and locations of thermocouple tips of the cane #3 are shown in Table 3.3 )

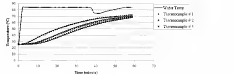


Figure 4.12 Comparison of measured and predicted temperatures at 3 locations within the cone # 3, Experiment II.

(The continuous lines are temperatures predicted using h = 140 W/ $m^2$ K, thermal conductivity = 0.19 W/m K, and thermal diffusivity = 1.09 x $10^{-7}$ $m^2$/s. Dimension and locations of thermocouple tips of the cone #3 are shown in Table 3.3.)

Sheen et al (1993) used an h value of 700 W/ $m^2$ K to simulate temperature within a bowl (big radius 4.2 cm, small radius 2.8 cm and height 5.7 cm) heated in a circulating superheated water-type retort at constant temperature of 120°C

The heat transfer coefficient required for a good agreement of the finite elliptical cylinder#1 was 1200-1300 W/ $m^2$ °C and the finite elliptical cylinder#2 was approximately 400 W/ $m^2$ °C According to Singh and Heldman (1993) the approximate value of convective heat transfer coefficient value of forced convection water (not boiling )could vary from 50-10 000 W/ $m^2$ °C Chau and Snyder (1988) measured the h value of a shrimp shaped aluminum casting (similar to a cone shape), heated in agitated hot water They reported the h values decreased from 5472 to 3478 W/ $m^2$ K when the radius increased from 6.35 to 8.75 mm This study should support the contention that the variation of the heat transfer coefficient in this study is mostly due to differences to shape and size of the acrylic models

It could be concluded that the close agreement of replicate experimental and simulated temperature profiles of 3-4 points within different shapes and sizes of the cone and finite elliptical cylinder models provided sufficient evidence to validate their accuracy

## Study of Optimization of Quality Retention

The cone and finite elliptical cylinder models were further modified to calculate the volume average quality retention of foods during thermal processing. A number of simulations were performed with primary emphasis on a clear understanding of the influence of various parameters on the maximum quality retention Six Z values (10, 20

30 40 50 and 60 °C ) and six $D_{ref}$ values (40 80 120 160, 200 and 240 minutes) resulting in 36 combinations of quality factors covering the broad range of kinetic parameters found in the literature were considered The rate of thermal destruction of these quality factors was assumed to follow first order kinetics The effects of processing conditions (retort temperature, surface heat transfer coefficient, and container geometries ) and the thermal diffusivity of foods, as summarized in Table 3 5 was systematically investigated Three equal-volume conically shaped containers with different geometries and two typical commercial finite elliptically shaped containers with dimensions given in Table 3 6 and 3 7 were used in the simulations Internal heat transfer was conduction only It is assumed that the temperature at the surface of the object being heated is constant and thermal diffusivity of the object is constant over the temperature ranges under consideration

### Cold Point of the Conically Shaped Container

In this study the cold point at any given time was defined as the point of the least accumulated $F_o$ at that time Because conduction heating food in a conically shaped container is heated asymmetrically the position of the cold point depends on the container geometry

Figure 4 13 shows the simulation of temperature distribution along the axis of the 3 conically shaped containers during heating for 30 minutes at 10 minute intervals in a constant 120°C heating medium under an infinite heat transfer coefficient condition The position index indicates the location along the axis from the small radius (position index = 0 0 )to the big radius (position index = 1 0) The effect of food thermal diffusivity at

1 2, 1 4 and 1 6 $m^2$/sec on the cold point location is also shown in the same figure The location of the cold point did not change over time during the heating of 10 to 30 minutes regardless of cone geometry or thermal diffusivity The position indices of the cold point for the cone #1 #2 and #3 were 0 58 0 50and 0 71 respectively

The cold point location during heating for all conical shapes did not change when the heat transfer coefficient changed from 300 W $m^2$ / K to infinite h (Figure 4 14) With an infinite heat transfer coefficient condition, the temperatures at the position indices of 0 0 and 1 0 were equal to the heating medium temperature. As the heat transfer coefficient decreased, the temperature of all points along the rotation axis decreased

The simulation results indicated that the position of the least $F_o$ may change after cooling has started depending on cone geometry and may not be at the cold point during heating Since the cold point is cooled more slowly the contribution of $F_o$ is still at a high rate and the total accumulated $F_o$ at this point may be higher than the total $F_o$ of other points along the axis In order to find the processing time that gives the desired $F_o$ value it is important to keep track of the position of the least $F_o$ for the entire process and compare it with the target $F_o$ to ensure the safety of the product

## Processing Time for Equivalent Lethality

The simulations assumed that food was heated from the initial temperature ( 22 °C) and cooled down until the cold point temperature was less than 50 °C The lethality ($F_o$) of 3 minutes which could ensure safety from *Clostridium botulinum* was used as a constraint in the simulations

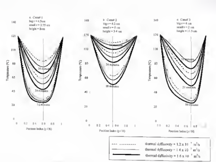


Figure 4.13 Effect of thermal diffusivity and processing time on simulated temperature distributions along the rotating axis for conduction heating food in the conically shaped containers processed under infinite heat transfer coefficient condition retort temperature = 120°C

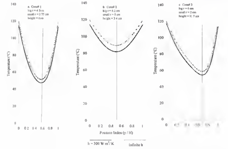


Figure 4.14 Effect of heat transfer coefficient on simulated temperature distributions along the rotating axis for conduction heated food in the conically shaped containers, thermal diffusivity = $1.4 \times 10^{-7}$ m²/s, retort temperature = 120°

The exact time for heating and cooling in order to obtain the desired $F_o$ value was found such that the total $F_o$ would be not exceed the desired $F_o$ by more than 0.0001 min. The total processing time was the sum of the heating and cooling time. The complete simulated heating, cooling and total processing time responding to different processing temperatures for both conical and elliptical containers were summarized in Appendix D (Table D-1 and D-2). The total time and corresponding retort temperature required for processing different container geometries were compared in Figure 4.15. Any point on these curves represents a thermal process that produces the same target $F_o$ of 3 minutes with the error less than 1%. Since the destruction rate of microorganisms has an exponential relationship with temperature, as expected, the relationship of retort temperature and processing time is also an exponential function. When a low retort temperature was used especially when it was far below the reference temperature (121.1 C), the longer processing time was required to reach a target $F_o$ because a very small lethality is contributed at each time interval. As the processing temperature was raised closer to the reference temperature, the processing time was significantly shortened and then it remained almost constant.

Among the conical containers of equivalent volume (approximately 336 $cm^3$), the cone # 2 which had the smallest volume-to-surface ratio (1.03) required the shortest processing time, followed by the cone #3 and #1 with ratios of 1.19 and 1.23 respectively.

Comparing between the finite elliptical cylinder#1 and #2, having volume of 515 and 308 $cm^3$, as expected, the finite elliptical cylinder # 1 required longer processing time

It is interesting to note that the finite elliptical cylinder #1, which has a bigger volume and equal volume/surface ratio(1.19) compared to the cone #3 required less processing time. This is because the finite elliptical cylinder #1 has a large symmetric top and bottom surface and a thin profile that makes heat transfer to the cold point faster. The simulation results lead to the conclusion that volume, surface area or even volume/surface area may not be enough for comparing rates of heat transfer in irregular containers. Simulation should be performed case by case in order to make a comparison.

Effects of thermal diffusivity (1.2, 1.4 and 1.6 x$10^{-7}$ $m^2/s$) and surface heat transfer coefficient (h= 300 W $m^2$/ K and infinite h ) on total processing time of foods packed in the cone #1 is illustrated in Figure 4.16. As supported by Figure 4.13a, increasing thermal diffusivity results in faster heating at the cold point, which then accelerates the temperature uniformity throughout the container and shortens the processing time. Increasing the heat transfer coefficient also increases the rate of heat transfer by increasing the surface temperature. In the case of cone #1, foods processed under infinite heat transfer coefficient conditions require 13-24 % less processing time than those processed under the finite heat transfer coefficient condition.

It should be noted that the contribution of $F_o$ during the cooling of conduction heating food is important especially when food is processed at high retort temperatures. In such cases, the temperature at the cold point is high when cooling starts and therefore it takes longer time to cool down. The ratio of heating to cooling time was almost 1:1

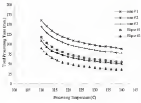


Figure 4 15 Simulated retort temperatures and total processing times of conduction heated foods having alpha = 1 4 m$^2$/s packed in different geometric containers giving equal $F_o$ value = 3 minutes ( based on z value = 10 minutes Initial temperature = 22 °C final temperature = 50 °C, infinite heat transfer coefficient condition)

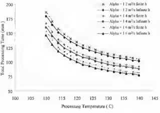


Figure 4 16 Simulated retort temperatures and total processing times of conduction heated foods having different thermal diffusivity packed in the conical shaped container #1 processed under finite and infinite heat transfer coefficient conditions giving equal $F_o$ value = 3 minutes ( based on z value = 10 minutes, Initial temperature = 22 °C final temperature = 50 °C)

## Investigation of Factors Affecting Quality Retention and Optimum Processing Temperature

All results of simulated overall retention of quality factors with different $D_{ref}$ and Z values in conduction heating foods with thermal diffusivity 1.2, 1.4 and 1.6 $m^2/s$ packed in 3 different conical shaped containers and 2 different elliptical shaped containers processed with constant temperature from 110 to 140 C using finite and infinite surface heat transfer coefficients are presented in Appendix E (Tables E1-E30). Optimum processing temperatures for maximizing quality retention of different geometries, thermal diffusivity and heat transfer coefficients are summarized in Tables 4.3-4.7.

### Z Value

The effect of changing the Z value of quality factors across the range of 10-60 ° C at 10 °C intervals and processing temperatures (110- 140 ° C) on the volume integrated retentions is illustrated in Figure 4.17. These simulations were performed with foods of thermal diffusivity 1.4 x $10^{-7}$ $m^2/s$ packed in the cone #1 and the $D_{ref}$ value of the quality factors was fixed at 200 minutes. The curve for depicting the effect of increasing temperature at each Z value had one optimum temperature($T_{opt}$) resulting in a maximum quality retention. The quality factor with a lower Z value had a lower $T_{opt}$. The results also indicated that percent retention of the quality factors with a low Z value are highly sensitive to a departure from the optimum temperature. Since these quality factors are very sensitive to temperature changes, their destruction rates changed dramatically when the temperature changed. When the processing temperature is higher than the optimum temperature, the effect of high temperature destruction overcomes the benefit of the high

Table 4.3 Optimum temperature for maximizing quality retention of conduction heated food after thermal processing in the elliptically shaped container # 1 (a = 8.10 cm, b = 5.32 cm, height = 3.81cm)

| Alpha | $D_{ref}$ | Z = 10°C |  | Z = 20°C |  | Z = 30°C |  | Z = 40°C |  | Z = 50°C |  | Z = 60°C |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ($m^2/s$) | (min) | $T_{opt}$ (°C) | NR(%) | $T_{opt}$ (°C) | NR(%) | $T_{opt}$ (°C) | NR(%) | $T_{opt}$ (°C) | NR(%) | $T_{opt}$ (°C) | NR(%) | $T_{opt}$ (°C) | NR(%) |
| a) h = 300 W / $m^2$K |  |  |  |  |  |  |  |  |  |  |  |  |  |
| $1.2 \times 10^{-7}$ | 40.00 | 110.00 | 76.50 | 113.03 | 32.50 | 121.35 | 19.71 | 129.72 | 15.45 | 136.81 | 13.48 | 140.00 | 12.27 |
|  | 80.00 | 110.00 | 87.42 | 112.58 | 56.54 | 119.22 | 43.08 | 125.55 | 37.56 | 130.56 | 34.78 | 137.42 | 33.24 |
|  | 120.00 | 110.00 | 91.42 | 112.46 | 68.25 | 118.61 | 56.68 | 124.56 | 51.56 | 130.27 | 48.93 | 136.15 | 47.44 |
|  | 160.00 | 110.00 | 93.49 | 112.43 | 75.05 | 118.41 | 65.18 | 124.02 | 60.64 | 129.93 | 58.27 | 135.82 | 56.92 |
|  | 200.00 | 110.00 | 94.75 | 112.37 | 79.45 | 118.23 | 70.93 | 123.60 | 66.91 | 129.73 | 64.79 | 135.49 | 65.58 |
|  | 240.00 | 110.00 | 95.61 | 112.37 | 82.59 | 118.07 | 75.07 | 123.27 | 71.48 | 129.52 | 69.57 | 135.31 | 68.49 |
| $1.4 \times 10^{-7}$ | 40.00 | 110.00 | 77.49 | 113.60 | 35.12 | 121.62 | 22.67 | 129.85 | 18.44 | 137.56 | 16.42 | 140.00 | 15.22 |
|  | 80.00 | 110.00 | 88.00 | 113.12 | 58.84 | 119.70 | 46.50 | 125.94 | 41.42 | 131.50 | 38.91 | 138.40 | 37.47 |
|  | 120.00 | 110.00 | 91.82 | 113.83 | 70.12 | 119.39 | 59.72 | 125.22 | 55.15 | 130.78 | 52.85 | 137.82 | 51.50 |
|  | 160.00 | 110.00 | 93.80 | 112.94 | 76.58 | 118.91 | 67.81 | 124.77 | 63.82 | 130.36 | 61.79 | 136.75 | 60.59 |
|  | 200.00 | 110.00 | 95.01 | 112.97 | 80.76 | 118.79 | 73.23 | 124.62 | 69.45 | 130.24 | 67.94 | 136.21 | 66.87 |
|  | 240.00 | 110.00 | 95.82 | 112.91 | 83.68 | 118.76 | 77.18 | 124.41 | 73.99 | 130.18 | 72.41 | 135.46 | 71.45 |
| $1.6 \times 10^{-7}$ | 40.00 | 110.00 | 78.20 | 114.18 | 37.42 | 121.44 | 25.37 | 129.70 | 21.19 | 136.62 | 19.22 | 140.00 | 18.04 |
|  | 80.00 | 110.00 | 88.40 | 113.69 | 60.81 | 120.15 | 49.43 | 126.22 | 44.72 | 132.85 | 42.40 | 138.47 | 41.15 |
|  | 120.00 | 110.00 | 92.11 | 113.57 | 71.68 | 119.88 | 62.26 | 125.58 | 58.13 | 131.20 | 56.05 | 137.88 | 54.93 |
|  | 160.00 | 110.00 | 94.02 | 113.48 | 77.88 | 119.76 | 69.98 | 125.40 | 66.40 | 130.90 | 64.62 | 137.59 | 63.63 |
|  | 200.00 | 110.00 | 95.18 | 113.45 | 81.84 | 119.61 | 75.10 | 125.22 | 72.01 | 130.51 | 70.43 | 137.47 | 69.56 |
|  | 240.00 | 110.00 | 95.97 | 113.45 | 84.61 | 119.61 | 78.74 | 124.95 | 76.01 | 130.54 | 74.62 | 137.17 | 73.85 |

Table 4.3 (cont)

| Alpha | $D_{ref}$ | Z = 10°C |  | Z = 20°C |  | Z = 30°C |  | Z = 40°C |  | Z = 50°C |  | Z = 60°C |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ($m^2$/sec) | (min) | T (°C) | NR(%) | T (°C) | NR(%) | T (°C) | NR(%) | T (°C) | NR(%) | T (°C) | NR(%) | T (°C) | NR(%) |
| b.) Infinite h |  |  |  |  |  |  |  |  |  |  |  |  |  |
| $1.2 \times 10^{-7}$ | 40.00 | 110.00 | 76.47 | 113.00 | 33.52 | 120.66 | 21.15 | 129.25 | 17.13 | 136.99 | 15.31 | 140.00 | 14.14 |
|  | 80.00 | 110.00 | 87.40 | 112.58 | 57.37 | 118.65 | 44.60 | 124.62 | 39.47 | 130.39 | 36.96 | 136.85 | 35.60 |
|  | 120.00 | 110.00 | 91.60 | 112.43 | 68.91 | 118.23 | 58.00 | 123.90 | 53.28 | 129.49 | 50.91 | 135.22 | 49.63 |
|  | 160.00 | 110.00 | 93.47 | 112.40 | 75.57 | 118.04 | 66.31 | 123.63 | 62.13 | 128.92 | 60.02 | 134.50 | 58.87 |
|  | 200.00 | 110.00 | 94.74 | 112.34 | 79.90 | 117.93 | 71.90 | 123.45 | 68.22 | 128.53 | 66.34 | 134.08 | 65.32 |
|  | 240.00 | 110.00 | 95.60 | 112.34 | 83.93 | 117.83 | 75.92 | 123.27 | 72.63 | 128.10 | 70.96 | 133.75 | 70.04 |
| $1.4 \times 10^{-7}$ | 40.00 | 110.00 | 77.48 | 113.78 | 36.34 | 121.41 | 24.45 | 129.16 | 20.47 | 136.21 | 18.89 | 140.00 | 17.61 |
|  | 80.00 | 110.00 | 87.99 | 113.30 | 59.81 | 119.23 | 48.19 | 125.52 | 45.58 | 130.48 | 41.37 | 136.51 | 40.19 |
|  | 120.00 | 110.00 | 91.81 | 113.15 | 70.66 | 118.71 | 61.15 | 124.59 | 57.02 | 129.79 | 55.04 | 135.58 | 53.96 |
|  | 160.00 | 110.00 | 93.79 | 113.12 | 77.18 | 118.44 | 69.02 | 123.88 | 65.44 | 129.49 | 63.69 | 135.25 | 62.47 |
|  | 200.00 | 110.00 | 95.00 | 113.06 | 81.26 | 118.31 | 74.27 | 123.57 | 71.13 | 129.28 | 69.59 | 134.77 | 68.76 |
|  | 240.00 | 110.00 | 95.82 | 113.03 | 84.11 | 118.29 | 78.00 | 123.27 | 75.23 | 128.83 | 73.66 | 134.77 | 73.12 |
| $1.6 \times 10^{-7}$ | 40.00 | 110.00 | 78.26 | 114.23 | 38.75 | 121.59 | 27.46 | 128.23 | 23.66 | 135.55 | 21.87 | 140.00 | 20.92 |
|  | 80.00 | 110.00 | 88.44 | 113.78 | 61.83 | 119.94 | 51.28 | 125.85 | 47.13 | 131.53 | 45.17 | 136.90 | 44.17 |
|  | 120.00 | 110.00 | 92.13 | 113.63 | 72.45 | 119.37 | 63.78 | 125.19 | 60.36 | 130.33 | 58.44 | 135.48 | 57.57 |
|  | 160.00 | 110.00 | 94.03 | 113.54 | 78.50 | 119.24 | 71.26 | 124.62 | 68.15 | 128.81 | 66.66 | 134.95 | 65.91 |
|  | 200.00 | 110.00 | 95.20 | 113.51 | 82.37 | 119.81 | 76.19 | 124.29 | 73.50 | 129.40 | 72.21 | 135.07 | 71.55 |
|  | 240.00 | 110.00 | 95.98 | 113.51 | 85.07 | 119.87 | 79.69 | 124.08 | 77.33 | 129.21 | 76.18 | 134.26 | 75.61 |

Table 4.4 Optimum temperature for maximizing quality retention of conduction heated food after thermal processing in the elliptically shaped container # 2 (a = 7.46 cm, b = 4.46 cm, height = 2.96 cm)

| Alpha | $D_{cd}$ | Z = 10°C | | Z = 20°C | | Z = 30°C | | Z = 40°C | | Z = 50°C | | Z = 60°C | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m²/s) | (min) | $T_{max}$(°C) | NR(%) | $T_{max}$(°C) | NR(%) | $T_{max}$(°C) | NR(%) | $T_{max}$(°C) | NR(%) | $T_{max}$(°C) | NR(%) | $T_{max}$(°C) | NR(%) |
| a.) h = 300 W / m² K | | | | | | | | | | | | | |
| $1.2 \times 10^{-7}$ | 40.00 | 110.00 | 79.06 | 114.98 | 40.43 | 122.76 | 29.32 | 129.88 | 25.41 | 137.47 | 23.62 | 140.00 | 22.54 |
| | 80.00 | 110.00 | 88.90 | 114.53 | 63.24 | 121.35 | 53.24 | 127.63 | 49.25 | 132.85 | 47.33 | 140.00 | 46.32 |
| | 120.00 | 110.00 | 92.45 | 114.41 | 71.59 | 120.98 | 65.50 | 127.06 | 62.95 | 132.25 | 60.41 | 138.85 | 59.51 |
| | 160.00 | 110.00 | 94.28 | 114.35 | 79.42 | 120.72 | 72.67 | 126.60 | 69.78 | 132.13 | 68.38 | 138.23 | 67.62 |
| | 200.00 | 110.00 | 95.40 | 114.29 | 83.15 | 120.57 | 77.42 | 126.33 | 74.92 | 131.92 | 73.71 | 137.98 | 73.05 |
| | 240.00 | 110.00 | 96.15 | 114.29 | 85.73 | 120.57 | 80.76 | 126.30 | 78.58 | 131.95 | 77.51 | 137.72 | 76.93 |
| $1.4 \times 10^{-7}$ | 40.00 | 110.00 | 79.73 | 115.79 | 43.05 | 122.91 | 32.59 | 130.66 | 28.95 | 137.84 | 27.35 | 140.00 | 26.36 |
| | 80.00 | 110.00 | 89.28 | 115.34 | 64.00 | 121.77 | 56.35 | 128.11 | 52.80 | 134.29 | 51.20 | 140.00 | 50.40 |
| | 120.00 | 110.00 | 92.71 | 115.19 | 75.19 | 121.47 | 68.80 | 127.32 | 60.06 | 133.63 | 63.71 | 140.00 | 63.05 |
| | 160.00 | 110.00 | 94.48 | 115.22 | 80.72 | 121.32 | 74.82 | 127.06 | 72.34 | 133.24 | 71.20 | 137.00 | 70.38 |
| | 200.00 | 110.00 | 95.56 | 115.13 | 84.24 | 121.17 | 79.25 | 126.94 | 77.12 | 133.30 | 76.14 | 138.85 | 75.68 |
| | 240.00 | 110.00 | 96.29 | 115.07 | 86.64 | 121.20 | 82.36 | 126.73 | 80.51 | 133.00 | 79.65 | 138.50 | 79.23 |
| $1.6 \times 10^{-7}$ | 40.00 | 110.00 | 80.21 | 116.39 | 45.24 | 123.99 | 35.99 | 130.75 | 32.88 | 137.95 | 30.59 | 140.00 | 29.67 |
| | 80.00 | 110.00 | 89.55 | 116.03 | 66.90 | 122.79 | 58.85 | 129.28 | 55.77 | 135.16 | 54.39 | 140.00 | 53.68 |
| | 120.00 | 110.00 | 92.90 | 115.94 | 76.49 | 122.19 | 71.69 | 128.11 | 67.53 | 134.29 | 66.39 | 140.00 | 65.83 |
| | 160.00 | 110.00 | 94.61 | 115.91 | 81.76 | 121.98 | 76.54 | 127.48 | 74.40 | 134.26 | 73.45 | 140.00 | 72.98 |
| | 200.00 | 110.00 | 95.68 | 115.88 | 85.11 | 121.86 | 80.71 | 127.26 | 78.89 | 133.99 | 78.07 | 140.00 | 77.88 |
| | 240.00 | 110.00 | 96.39 | 115.88 | 87.42 | 121.84 | 83.62 | 127.06 | 82.04 | 133.84 | 81.34 | 140.00 | 80.99 |

Table 4.4 (cont)

| Alpha | $D_{ref}$ | Z = 10°C | | Z = 20°C | | Z = 30°C | | Z = 40°C | | Z = 50°C | | Z = 60°C | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m²/sec) | (min) | T (°C) | NR(%) | T (°C) | NR(%) | T (°C) | NR(%) | T (°C) | NR(%) | T (°C) | NR(%) | T (°C) | NR(%) |
| b.) Infinite h | | | | | | | | | | | | | |
| $1.2 \times 10^{-7}$ | 40.00 | 110.00 | 80.32 | 114.74 | 41.37 | 121.62 | 30.60 | 128.67 | 26.81 | 134.32 | 25.05 | 140.00 | 24.11 |
| | 80.00 | 110.00 | 89.61 | 114.23 | 63.97 | 120.36 | 54.44 | 126.06 | 50.65 | 133.45 | 48.85 | 137.80 | 47.99 |
| | 120.00 | 110.00 | 92.94 | 114.11 | 74.16 | 119.96 | 66.45 | 125.55 | 63.23 | 130.09 | 61.73 | 136.90 | 60.88 |
| | 160.00 | 110.00 | 94.66 | 114.02 | 79.88 | 119.79 | 73.51 | 125.40 | 70.79 | 130.00 | 69.51 | 134.88 | 68.80 |
| | 200.00 | 110.00 | 95.70 | 113.99 | 83.53 | 119.70 | 78.13 | 125.01 | 75.78 | 129.82 | 74.69 | 134.86 | 74.07 |
| | 240.00 | 110.00 | 96.41 | 113.99 | 83.59 | 119.70 | 78.13 | 125.01 | 75.78 | 129.82 | 74.69 | 134.86 | 74.07 |
| $1.4 \times 10^{-7}$ | 40.00 | 110.00 | 79.75 | 115.52 | 44.19 | 122.28 | 34.16 | 128.32 | 30.66 | 135.07 | 29.06 | 138.23 | 28.23 |
| | 80.00 | 110.00 | 89.29 | 115.13 | 66.16 | 121.11 | 57.70 | 126.73 | 54.41 | 131.71 | 52.92 | 137.29 | 52.28 |
| | 120.00 | 110.00 | 92.72 | 115.01 | 75.85 | 120.69 | 69.11 | 125.85 | 66.40 | 130.99 | 65.16 | 136.93 | 64.57 |
| | 160.00 | 110.00 | 94.49 | 114.95 | 81.24 | 120.57 | 75.73 | 125.67 | 73.46 | 130.81 | 72.41 | 137.00 | 71.66 |
| | 200.00 | 110.00 | 95.57 | 114.89 | 84.67 | 120.48 | 80.01 | 125.37 | 77.00 | 130.48 | 77.19 | 136.39 | 76.77 |
| | 240.00 | 110.00 | 96.29 | 114.86 | 87.04 | 120.39 | 83.02 | 125.25 | 81.34 | 130.51 | 80.57 | 136.54 | 80.18 |
| $1.6 \times 10^{-7}$ | 40.00 | 110.00 | 80.32 | 116.03 | 46.56 | 122.73 | 37.24 | 128.89 | 34.00 | 134.77 | 32.59 | 140.30 | 31.90 |
| | 80.00 | 110.00 | 89.61 | 115.76 | 67.95 | 121.23 | 60.40 | 126.57 | 57.54 | 131.98 | 56.28 | 137.62 | 55.66 |
| | 120.00 | 110.00 | 92.94 | 115.67 | 77.23 | 120.99 | 71.29 | 126.15 | 68.98 | 131.56 | 67.95 | 136.99 | 67.46 |
| | 160.00 | 110.00 | 94.66 | 115.61 | 82.35 | 120.84 | 77.53 | 125.94 | 75.61 | 131.35 | 74.75 | 136.72 | 74.34 |
| | 200.00 | 110.00 | 95.70 | 115.58 | 85.60 | 120.84 | 81.54 | 125.82 | 79.92 | 131.23 | 79.18 | 136.72 | 78.84 |
| | 240.00 | 110.00 | 96.41 | 115.55 | 87.83 | 120.72 | 84.34 | 125.79 | 82.94 | 131.23 | 82.30 | 136.63 | 82 |

Table 4.5 Optimum temperature for maximizing quality retention of conduction heated food after thermal processing in the conically shaped container #1 (top radius = 4.5 cm, bottom radius = 2.7 cm, height = 8 cm)

| Alpha ($m^2$/s) | $D_{ref}$ (min) | Z = 10°C | | Z = 20°C | | Z = 30°C | | Z = 40°C | | Z = 50°C | | Z = 60°C | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $T_{opt}$(°C) | NR(%) | $T_{opt}$(°C) | NR(%) | $T_{opt}$(°C) | NR(%) | $T_{opt}$(°C) | NR(%) | $T_{opt}$(°C) | NR(%) | $T_{opt}$(°C) | NR(%) |
| a.) h = 300 W / $m^2$K | | | | | | | | | | | | | |
| $1.2 \times 10^{-7}$ | 40.00 | 110.00 | 75.10 | 112.22 | 29.30 | 128.93 | 16.99 | 130.93 | 11.85 | 134.53 | 9.69 | 136.03 | 8.22 |
| | 80.00 | 110.00 | 86.58 | 111.95 | 53.46 | 118.11 | 38.28 | 124.83 | 31.96 | 131.53 | 28.80 | 134.41 | 26.92 |
| | 120.00 | 110.00 | 90.82 | 111.89 | 65.68 | 117.50 | 52.27 | 123.93 | 46.00 | 138.39 | 42.82 | 134.05 | 40.84 |
| | 160.00 | 110.00 | 93.03 | 111.83 | 72.88 | 117.21 | 61.26 | 122.40 | 55.62 | 129.22 | 52.58 | 133.72 | 50.78 |
| | 200.00 | 110.00 | 94.38 | 111.83 | 77.60 | 117.08 | 67.47 | 122.07 | 62.40 | 128.68 | 59.60 | 133.54 | 57.94 |
| | 240.00 | 110.00 | 95.29 | 111.88 | 80.92 | 116.97 | 71.98 | 121.86 | 67.41 | 128.32 | 64.85 | 133.42 | 63.38 |
| $1.4 \times 10^{-7}$ | 40.00 | 110.00 | 76.47 | 112.22 | 32.11 | 121.44 | 18.93 | 128.17 | 14.43 | 134.20 | 12.06 | 137.18 | 10.53 |
| | 80.00 | 110.00 | 87.39 | 112.04 | 56.14 | 120.78 | 41.91 | 124.62 | 36.06 | 129.94 | 32.83 | 135.48 | 30.76 |
| | 120.00 | 110.00 | 91.39 | 111.98 | 67.91 | 118.62 | 55.62 | 123.63 | 50.11 | 128.73 | 46.99 | 134.23 | 45.02 |
| | 160.00 | 110.00 | 93.47 | 111.95 | 74.75 | 118.35 | 64.23 | 123.18 | 59.32 | 128.17 | 56.49 | 133.75 | 54.71 |
| | 200.00 | 110.00 | 94.74 | 111.95 | 79.20 | 118.20 | 70.08 | 122.94 | 65.73 | 127.77 | 63.18 | 133.51 | 61.59 |
| | 240.00 | 110.00 | 95.59 | 111.92 | 82.32 | 118.11 | 74.31 | 122.76 | 70.41 | 127.54 | 68.13 | 133.39 | 66.69 |
| $1.6 \times 10^{-7}$ | 40.00 | 110.00 | 77.36 | 112.97 | 34.22 | 122.40 | 21.90 | 128.89 | 17.27 | 136.18 | 14.97 | 136.33 | 13.33 |
| | 80.00 | 110.00 | 87.91 | 112.52 | 58.81 | 119.88 | 45.32 | 125.49 | 39.79 | 131.50 | 36.84 | 140.00 | 35.16 |
| | 120.00 | 119.00 | 91.76 | 112.43 | 69.43 | 119.49 | 58.54 | 124.53 | 53.60 | 138.27 | 50.85 | 137.18 | 49.26 |
| | 160.00 | 110.00 | 93.75 | 112.37 | 76.81 | 119.25 | 66.77 | 124.11 | 62.44 | 129.67 | 59.98 | 136.51 | 58.57 |
| | 200.00 | 110.00 | 94.97 | 112.34 | 80.28 | 119.10 | 72.31 | 123.87 | 68.50 | 129.28 | 66.31 | 136.21 | 65.07 |
| | 240.00 | 110.00 | 95.79 | 112.34 | 83.26 | 119.91 | 76.27 | 123.69 | 72.89 | 129.00 | 70.93 | 135.97 | 69.83 |

Table 4.5 (cont)

| Alpha (m²/sec) | $D_{ref}$ (mm) | Z = 10°C |  | Z = 20°C |  | Z = 30°C |  | Z = 40°C |  | Z = 50°C |  | Z = 60°C |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | T (°C) | NR(%) | T (°C) | NR(%) | T (°C) | NR(%) | T (°C) | NR(%) | T (°C) | NR(%) | T (°C) | NR(%) |
| b.) Influence b |  |  |  |  |  |  |  |  |  |  |  |  |  |
| $1.2 \times 10^{-7}$ | 40.00 | 110.00 | 74.51 | 115.53 | 28.43 | 120.54 | 15.98 | 132.22 | 11.56 | 135.64 | 9.53 | 136.87 | 8.16 |
|  | 80.00 | 110.00 | 86.22 | 110.60 | 52.66 | 117.98 | 37.96 | 122.49 | 31.77 | 127.98 | 28.28 | 134.65 | 26.42 |
|  | 120.00 | 110.00 | 90.59 | 110.00 | 95.05 | 117.38 | 51.88 | 121.53 | 45.68 | 125.97 | 42.35 | 133.01 | 40.42 |
|  | 160.00 | 110.00 | 92.83 | 110.00 | 72.37 | 117.11 | 66.89 | 121.17 | 55.45 | 125.31 | 52.23 | 133.09 | 59.33 |
|  | 200.00 | 110.00 | 94.21 | 110.00 | 77.18 | 116.99 | 67.12 | 129.93 | 62.23 | 124.95 | 59.30 | 132.55 | 57.55 |
|  | 240.00 | 110.00 | 95.15 | 110.00 | 80.56 | 116.87 | 71.98 | 120.78 | 97.26 | 124.71 | 64.60 | 132.04 | 62.98 |
| $1.4 \times 10^{-7}$ | 40.00 | 110.00 | 75.76 | 112.13 | 31.53 | 119.95 | 10.54 | 129.10 | 14.24 | 135.25 | 12.22 | 138.80 | 10.83 |
|  | 80.00 | 110.00 | 86.97 | 111.86 | 55.53 | 117.42 | 41.56 | 123.54 | 35.95 | 130.21 | 32.69 | 134.71 | 30.94 |
|  | 120.00 | 110.00 | 91.09 | 111.74 | 97.39 | 119.91 | 55.28 | 122.31 | 49.91 | 128.73 | 46.78 | 133.36 | 45.12 |
|  | 160.00 | 110.00 | 93.24 | 111.68 | 74.31 | 119.67 | 63.92 | 121.80 | 58.85 | 128.11 | 56.27 | 132.79 | 54.77 |
|  | 200.00 | 110.00 | 94.55 | 111.65 | 78.82 | 116.54 | 69.82 | 121.50 | 65.31 | 127.72 | 62.97 | 132.40 | 61.63 |
|  | 240.00 | 110.00 | 95.43 | 111.95 | 81.99 | 116.45 | 74.07 | 121.29 | 78.04 | 127.45 | 67.92 | 132.19 | 66.72 |
| $1.9 \times 10^{-7}$ | 40.00 | 110.00 | 76.61 | 113.24 | 34.17 | 119.61 | 21.47 | 125.34 | 16.97 | 135.46 | 14.73 | 136.73 | 13.33 |
|  | 80.00 | 110.00 | 87.47 | 112.73 | 57.85 | 118.17 | 49.99 | 122.40 | 39.22 | 131.38 | 36.20 | 135.35 | 34.77 |
|  | 120.00 | 110.00 | 91.45 | 112.91 | 69.26 | 117.75 | 54.35 | 121.74 | 53.12 | 128.11 | 50.22 | 134.52 | 48.89 |
|  | 160.00 | 110.00 | 93.51 | 112.52 | 75.86 | 117.60 | 66.91 | 121.40 | 62.30 | 127.08 | 59.42 | 134.11 | 58.21 |
|  | 200.00 | 110.00 | 94.77 | 112.49 | 80.14 | 117.48 | 72.17 | 121.23 | 68.13 | 126.60 | 65.82 | 133.84 | 64.73 |
|  | 240.00 | 119.00 | 95.62 | 112.49 | 83.13 | 117.47 | 78.15 | 121.11 | 72.58 | 126.39 | 70.50 | 133.66 | 99.52 |

Table 4.6 Optimum temperature for maximizing quality retention of conduction heated food after thermal processing in the conically shaped container # 2 (top radius = 6.2 cm, bottom radius = 5 cm, height = 3.40 cm)

| Alpha | $D_{ref}$ | Z = 10°C | | Z = 20°C | | Z = 30°C | | Z = 40°C | | Z = 50°C | | Z = 60°C | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m²/s) | (min) | T (°C) | NR(%) | T (°C) | NR(%) | T (°C) | NR(%) | T (°C) | NR(%) | T (°C) | NR(%) | T (°C) | NR(%) |
| a.) h = 300 W / m² K | | | | | | | | | | | | | |
| $1.2 \times 10^{-7}$ | 40.00 | 116.00 | 77.74 | 113.66 | 36.04 | 120.90 | 24.24 | 127.47 | 19.82 | 138.84 | 17.93 | 140.00 | 16.77 |
| | 80.00 | 116.00 | 88.14 | 113.42 | 59.85 | 119.52 | 48.22 | 124.74 | 43.19 | 132.16 | 40.67 | 139.76 | 39.47 |
| | 120.00 | 118.00 | 91.92 | 113.30 | 70.89 | 119.16 | 61.22 | 123.96 | 56.78 | 136.87 | 54.44 | 137.62 | 53.37 |
| | 160.00 | 116.00 | 93.88 | 113.24 | 77.21 | 119.61 | 69.10 | 123.57 | 65.26 | 139.15 | 63.19 | 137.28 | 62.27 |
| | 200.00 | 110.00 | 95.07 | 113.21 | 81.27 | 118.89 | 74.34 | 123.36 | 70.99 | 129.76 | 69.16 | 136.99 | 68.36 |
| | 240.00 | 110.00 | 95.87 | 113.15 | 84.12 | 118.83 | 78.07 | 123.24 | 75.12 | 129.46 | 73.49 | 136.87 | 72.78 |
| $1.4 \times 10^{-7}$ | 40.00 | 110.00 | 78.53 | 114.29 | 38.97 | 121.08 | 27.10 | 136.96 | 23.14 | 136.24 | 21.46 | 138.58 | 20.16 |
| | 80.00 | 116.00 | 88.60 | 113.93 | 62.87 | 119.76 | 51.23 | 126.48 | 46.71 | 134.53 | 44.97 | 137.15 | 43.84 |
| | 120.00 | 110.00 | 92.24 | 113.81 | 72.67 | 119.39 | 63.81 | 125.25 | 59.86 | 134.85 | 58.29 | 136.84 | 57.41 |
| | 160.00 | 116.00 | 94.12 | 113.75 | 78.66 | 119.25 | 71.31 | 124.74 | 67.92 | 133.83 | 66.54 | 136.69 | 65.83 |
| | 200.00 | 116.00 | 95.27 | 113.72 | 82.51 | 119.16 | 76.25 | 124.44 | 73.31 | 133.69 | 72.09 | 136.68 | 71.51 |
| | 240.00 | 110.00 | 96.04 | 113.69 | 85.19 | 119.06 | 79.75 | 124.26 | 77.17 | 133.63 | 76.08 | 136.57 | 75.56 |
| $1.6 \times 10^{-7}$ | 40.00 | 110.00 | 79.06 | 115.25 | 40.98 | 122.97 | 30.17 | 128.52 | 26.17 | 134.86 | 24.36 | 135.04 | 22.89 |
| | 80.00 | 116.00 | 88.90 | 114.86 | 63.66 | 126.84 | 54.15 | 126.15 | 50.08 | 137.68 | 48.29 | 140.00 | 47.62 |
| | 120.00 | 118.00 | 92.45 | 114.41 | 73.98 | 120.81 | 66.18 | 125.70 | 62.84 | 136.78 | 61.13 | 140.00 | 60.66 |
| | 160.00 | 118.00 | 94.28 | 114.32 | 79.66 | 126.63 | 73.29 | 125.49 | 70.46 | 130.88 | 68.98 | 140.00 | 68.60 |
| | 200.00 | 118.00 | 95.40 | 114.26 | 83.35 | 129.54 | 77.94 | 125.37 | 75.51 | 131.38 | 74.24 | 140.00 | 73.90 |
| | 240.00 | 118.00 | 96.15 | 114.23 | 85.91 | 120.45 | 81.22 | 125.28 | 79.10 | 131.88 | 77.98 | 140.00 | 77.67 |

Table 4.6 (cont)

| Alpha | $D_{sd}$ | Z = 10°C | | Z = 20°C | | Z = 30°C | | Z = 40°C | | Z = 50°C | | Z = 60°C | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ($m^2$/sec) | (mm) | $T_{max}$(°C) | NR(%) | $T_{max}$(°C) | NR(%) | $T_{max}$(°C) | NR(%) | $T_{max}$(°C) | NR(%) | $T_{max}$(°C) | NR(%) | $T_{max}$(°C) | NR(%) |
| b.) Infinite h | | | | | | | | | | | | | |
| $1.2 \times 10^{-7}$ | 40.00 | 110.00 | 77.56 | 113.93 | 36.65 | 120.21 | 25.14 | 124.98 | 28.65 | 135.25 | 18.79 | 136.66 | 17.60 |
| | 80.00 | 110.00 | 88.83 | 113.45 | 61.06 | 119.09 | 49.09 | 123.18 | 44.24 | 131.50 | 41.68 | 135.67 | 40.61 |
| | 120.00 | 110.00 | 91.85 | 113.38 | 71.06 | 118.73 | 61.95 | 122.70 | 57.71 | 128.49 | 55.40 | 135.13 | 54.43 |
| | 160.00 | 110.00 | 93.82 | 113.24 | 77.34 | 118.58 | 69.72 | 122.46 | 66.07 | 127.71 | 64.05 | 134.80 | 63.19 |
| | 200.00 | 110.00 | 95.02 | 113.18 | 81.39 | 118.49 | 74.87 | 122.34 | 71.71 | 127.38 | 69.93 | 134.62 | 69.17 |
| | 240.00 | 110.00 | 95.83 | 113.18 | 84.22 | 118.43 | 78.54 | 122.25 | 75.75 | 127.21 | 74.18 | 134.44 | 73.50 |
| $1.4 \times 10^{-7}$ | 40.00 | 110.00 | 78.60 | 114.50 | 39.55 | 120.36 | 38.36 | 128.22 | 24.32 | 132.91 | 22.60 | 134.95 | 21.30 |
| | 80.00 | 110.00 | 88.63 | 114.08 | 62.51 | 119.28 | 52.39 | 124.80 | 48.10 | 131.23 | 46.29 | 133.93 | 45.14 |
| | 120.00 | 110.00 | 93.26 | 113.93 | 73.01 | 118.97 | 64.76 | 124.05 | 61.08 | 130.66 | 59.49 | 133.51 | 58.55 |
| | 160.00 | 110.00 | 94.14 | 113.87 | 78.95 | 118.79 | 72.09 | 123.72 | 68.97 | 130.33 | 67.59 | 133.33 | 66.81 |
| | 200.00 | 110.00 | 95.28 | 113.81 | 82.76 | 118.73 | 76.92 | 123.51 | 74.22 | 130.09 | 72.02 | 133.21 | 72.31 |
| | 240.00 | 110.00 | 96.05 | 113.81 | 85.40 | 118.67 | 80.33 | 123.42 | 77.96 | 130.00 | 76.90 | 133.12 | 76.33 |
| $1.6 \times 10^{-7}$ | 40.00 | 110.00 | 79.37 | 114.56 | 42.26 | 121.51 | 31.58 | 127.21 | 27.97 | 130.27 | 25.95 | 132.43 | 24.43 |
| | 80.00 | 110.00 | 89.07 | 114.14 | 64.71 | 120.18 | 55.38 | 125.85 | 51.86 | 129.31 | 50.05 | 131.59 | 49.70 |
| | 120.00 | 110.00 | 92.57 | 113.99 | 74.74 | 119.78 | 67.23 | 125.40 | 64.27 | 129.03 | 62.79 | 131.35 | 61.71 |
| | 160.00 | 110.00 | 94.37 | 113.83 | 80.35 | 119.60 | 74.15 | 125.22 | 71.66 | 128.89 | 70.43 | 131.22 | 68.87 |
| | 200.00 | 110.00 | 95.47 | 113.87 | 83.95 | 119.49 | 78.68 | 125.07 | 76.55 | 128.79 | 75.49 | 131.14 | 74.73 |
| | 240.00 | 110.00 | 96.21 | 113.84 | 86.41 | 119.43 | 81.87 | 124.98 | 80.00 | 128.76 | 79.08 | 131.11 | 78.43 |

Table 4.7 Optimum temperature for maximizing quality retention of conduction heated food after thermal processing in the conically shaped container # 3 (top radius = 4.0 cm, bottom radius = 2 cm, height = 11.5cm)

| Alpha | $D_{ref}$ | Z = 10°C | | Z = 20°C | | Z = 30°C | | Z = 40°C | | Z = 50°C | | Z = 60°C | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ($m^2/s$) | (min) | $T_{opt}$(°C) | NR(%) | $T_{opt}$(°C) | NR(%) | $T_{opt}$(°C) | NR(%) | $T_{opt}$(°C) | NR(%) | $T_{opt}$(°C) | NR(%) | $T_{opt}$(°C) | NR(%) |
| a.) h = 300 W / $m^2$K | | | | | | | | | | | | | |
| $1.2 \times 10^{-7}$ | 40.00 | 110 | 75.73 | 115.22 | 29.94 | 120.30 | 17.41 | 128.01 | 12.83 | 136.48 | 10.88 | 137.47 | 9.44 |
| | 80.00 | 110 | 96.96 | 111.53 | 54.30 | 118.53 | 40.21 | 123.42 | 33.90 | 132.46 | 30.72 | 138.39 | 28.96 |
| | 120.00 | 110 | 91.09 | 111.32 | 66.43 | 118.01 | 54.04 | 122.58 | 48.18 | 129.22 | 44.86 | 135.55 | 43.13 |
| | 160.00 | 110 | 93.24 | 111.23 | 73.52 | 117.77 | 62.85 | 122.19 | 57.57 | 128.13 | 54.54 | 135.04 | 52.93 |
| | 200.00 | 110 | 94.55 | 111.20 | 78.16 | 117.62 | 68.87 | 121.98 | 64.17 | 127.53 | 61.42 | 134.68 | 59.95 |
| | 240.00 | 110 | 95.43 | 111.14 | 81.81 | 117.56 | 73.23 | 121.83 | 69.02 | 127.20 | 66.53 | 134.44 | 65.19 |
| $1.4 \times 10^{-7}$ | 40.00 | 110 | 76.91 | 113.12 | 33.38 | 120.39 | 20.15 | 130.45 | 15.85 | 136.24 | 13.79 | 140.00 | 12.33 |
| | 80.00 | 110 | 87.65 | 112.73 | 57.27 | 118.40 | 43.65 | 125.76 | 37.93 | 132.31 | 35.23 | 136.57 | 33.49 |
| | 120.00 | 110 | 91.58 | 112.64 | 68.54 | 117.89 | 57.21 | 124.47 | 51.88 | 131.14 | 49.31 | 135.40 | 47.70 |
| | 160.00 | 110 | 93.61 | 112.58 | 75.53 | 117.65 | 65.63 | 123.90 | 60.91 | 130.54 | 58.59 | 134.83 | 57.17 |
| | 200.00 | 110 | 94.85 | 112.55 | 79.87 | 117.53 | 71.33 | 123.57 | 67.15 | 130.27 | 65.07 | 134.50 | 63.81 |
| | 240.00 | 110 | 95.69 | 112.52 | 82.90 | 117.41 | 75.42 | 123.39 | 71.88 | 130.03 | 69.83 | 134.26 | 68.69 |
| $1.6 \times 10^{-7}$ | 40.00 | 110 | 77.57 | 113.90 | 35.47 | 121.74 | 23.18 | 128.46 | 18.77 | 134.26 | 16.43 | 138.01 | 14.88 |
| | 80.00 | 110 | 88.04 | 113.36 | 59.08 | 119.88 | 46.92 | 125.85 | 41.78 | 130.99 | 39.03 | 135.40 | 37.18 |
| | 120.00 | 110 | 91.85 | 113.18 | 70.28 | 119.38 | 60.05 | 125.07 | 55.45 | 130.18 | 52.96 | 134.26 | 51.30 |
| | 160.00 | 110 | 93.82 | 113.12 | 76.71 | 119.13 | 68.08 | 124.71 | 64.08 | 129.81 | 66.90 | 133.78 | 60.44 |
| | 200.00 | 110 | 95.02 | 113.96 | 80.86 | 118.97 | 73.45 | 124.56 | 69.93 | 129.64 | 68.03 | 133.51 | 66.75 |
| | 240.00 | 110 | 95.83 | 113.03 | 83.76 | 118.88 | 77.29 | 124.38 | 74.17 | 129.48 | 72.48 | 133.33 | 71.35 |

Table 4.7 (cont)

| Alpha | $D_{rel}$ | Z = 10°C | | Z = 20°C | | Z = 30°C | | Z = 40°C | | Z = 50°C | | Z = 60°C | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ($m^2$/sec) | (min) | T (°C) | NR(%) | T (°C) | NR(%) | T (°C) | NR(%) | T (°C) | NR(%) | T (°C) | NR(%) | T (°C) | NR(%) |
| b.) Infinite k | | | | | | | | | | | | | |
| $1.2 \times 10^{7}$ | 40.00 | 110 | 74.76 | 112.53 | 29.56 | 119.51 | 16.97 | 126.30 | 12.79 | 131.51 | 10.56 | 135.10 | 9.13 |
| | 80.00 | 110 | 86.38 | 111.56 | 52.68 | 117.51 | 39.51 | 123.21 | 33.52 | 128.19 | 30.41 | 133.18 | 28.43 |
| | 120.00 | 110 | 90.68 | 111.20 | 65.88 | 116.93 | 53.38 | 122.19 | 47.84 | 127.08 | 44.58 | 131.44 | 42.63 |
| | 160.00 | 110 | 92.92 | 111.02 | 73.06 | 116.86 | 62.26 | 121.71 | 57.08 | 129.93 | 54.05 | 130.87 | 52.49 |
| | 200.00 | 110 | 94.29 | 110.90 | 77.76 | 116.51 | 68.34 | 121.44 | 63.71 | 128.75 | 60.69 | 130.54 | 59.56 |
| | 240.00 | 110 | 95.21 | 110.84 | 81.07 | 116.42 | 72.75 | 121.26 | 68.59 | 126.09 | 66.30 | 130.33 | 64.85 |
| $1.4 \times 10^{7}$ | 40.00 | 110 | 76.14 | 114.20 | 32.11 | 120.42 | 19.99 | 126.30 | 15.66 | 133.63 | 13.42 | 134.35 | 11.98 |
| | 80.00 | 110 | 87.20 | 111.68 | 56.34 | 118.46 | 42.23 | 123.60 | 37.79 | 128.26 | 34.85 | 135.19 | 33.05 |
| | 120.00 | 110 | 91.26 | 111.53 | 68.06 | 117.89 | 56.76 | 122.83 | 51.74 | 127.32 | 48.99 | 132.52 | 47.25 |
| | 160.00 | 110 | 93.36 | 111.44 | 74.89 | 117.65 | 65.22 | 122.46 | 60.78 | 126.87 | 58.32 | 131.68 | 56.76 |
| | 200.00 | 110 | 94.65 | 111.41 | 79.32 | 117.50 | 70.65 | 122.22 | 67.02 | 126.63 | 64.83 | 131.26 | 63.44 |
| | 240.00 | 110 | 95.52 | 111.41 | 82.43 | 117.41 | 75.07 | 122.10 | 71.57 | 126.45 | 69.61 | 131.05 | 68.37 |
| $1.6 \times 10^{-7}$ | 60.00 | 110 | 76.97 | 113.69 | 34.88 | 120.45 | 23.11 | 125.07 | 18.52 | 137.47 | 16.32 | 139.24 | 15.14 |
| | 80.00 | 110 | 87.68 | 113.03 | 58.46 | 119.04 | 46.76 | 123.15 | 41.57 | 127.65 | 38.61 | 137.53 | 37.17 |
| | 120.00 | 110 | 91.60 | 112.82 | 69.76 | 118.61 | 59.98 | 122.58 | 55.27 | 126.75 | 52.59 | 136.45 | 51.14 |
| | 160.00 | 110 | 93.62 | 112.70 | 76.27 | 118.44 | 67.92 | 122.31 | 63.91 | 126.36 | 61.57 | 135.04 | 60.23 |
| | 200.00 | 110 | 94.86 | 112.61 | 80.48 | 118.31 | 73.30 | 122.16 | 69.86 | 126.15 | 67.74 | 134.11 | 66.53 |
| | 240.00 | 110 | 95.70 | 112.55 | 83.43 | 118.25 | 77.15 | 122.04 | 74.06 | 125.97 | 72.22 | 133.45 | 71.14 |

temperature short time process and the integrated volume retention drops sharply From Figure 4 17, at a Z value = 10 °C, the optimum temperature giving the maximum retention of 94 4% occurs at 110 °C The retention drops from 94 4% to 37 1 % upon increasing the retort temperature from 110 to 140 °C

When the Z value increases the reduction rate of quality factors is more insensitive to changes in temperature The optimum temperature for maximizing the nutrients moved toward higher temperatures However as the Z value increases the profile of the curve flattens and the percent quality retention becomes less sensitive to deviations from the optimum temperature For these simulations, the quality factor of Z = 60 °C had an optimum temperature at 132 4°C (Table 4 3 b) and the percent retention at this point was 61 65 % The results from Table E-5 showed that using processing temperatures ranging from 122-140 °C, the corresponding quality retentions were not significantly different ( % retention = 59 9-61 7) The difference from the maximum retention was only ± 1% The attempt to find the optimal temperature to maximize these quality factors may not be practical since the improvement is minor

### $D_{ref}$.

The effect of changing the $D_{ref}$ value on volume average quality retention was investigated A plot of the percent quality retention as a function of processing temperature and $D_{ref}$ value ranging from 40 to 240 minutes at 40 minute intervals, with a Z value constant at 30 °C, is presented in Figure 4 18 These simulations were performed assuming food with thermal diffusivity of 1 4x10$^{-7}$ m$^2$/s packed in the cone #1 The simulation results confirm the finding of Teixeira et al (1969) and Silva et al (1992) for

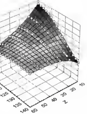


Figure 4.17 Effect of Z value (°C) and processing temperature (°C) on estimated retention of quality factor with $D_{ref}$ = 200 min in conduction heated food having thermal diffusivity 1.4 x $10^{-7}$ $m^2/s$ packed in the conically shaped container #1 processed under infinite heat transfer coefficient condition

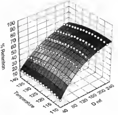


Figure 4.18 Effect of $D_{ref}$ value and processing temperature (°C) on estimated retention of quality factor with Z value = 30 °C in conduction heated food having thermal diffusivity 1.4 x $10^{-7}$ $m^2/s$ packed in the conically shaped container #1 processed under infinite heat transfer coefficient condition

conduction heated food in cylindrical container quality retention increases when $D_{ref}$ value increases at all processing temperatures From Table 4 3 b the maximum quality retention increases from 24 45 to 78 00 % when $D_{ref}$ increases from 40 to 240 minutes The $D_{ref}$ value had little influence on optimum temperatures When $D_{ref}$ ranges from 120 to 240 minutes the corresponding optimum temperatures were almost constant at approximately 116 °C However the quality factor with low $D_{ref}$ values had a slightly lower optimal temperature The maximum percent retention at $D_{ref}$ = 40 and 80 minutes occurred at the temperatures of 119 95 and 117 42 °C respectively These results agree with Silva et al (1992), who also found that the $D_{ref}$ value lower than 150 minutes had an effect on the optimal temperature of a conduction heating food in a cylindrical can.

With a low $D_{ref}$ value and a high Z value the temperature required to maximize quality retention is high However retention of quality factors having such kinetic parameters is extremely limited at any temperatures The maximum retention for that of $D_{ref}$ = 40 minutes and Z = 60 °C was only 10 83% Similar trends regarding optimum temperature as a function of $D_{ref}$ were observed for different values of Z, thermal diffusivity and other processing conditions.

Thermal Diffusivity

The effect of thermal diffusivity of 1 2, 1 4 and 1 6 x$10^{-7}$ $m^2$/sec, which is the range for most foods, on the volume integrated quality retention was investigated The 3-D plot of percent retention as a function of thermal diffusivity and processing temperature is presented in Figure 4 19 The simulations were performed with foods packed in the cone #1 under an infinite heat transfer coefficient for a quality factor with $D_{ref}$ = 200 minutes

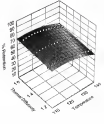


Figure 4.19 Effect of thermal diffusivity (x$10^{-7}$ $m^2/s$) and processing temperature (°C) on estimated retention of quality factor with Z value = 30 °C and $D_{ref}$ value = 200 min packed in the conically shaped container #1, processed under infinite heat transfer coefficient condition

and Z = 30 °C, which corresponds to a range of kinetic parameters for vitamins (Table 2.2). Foods with a higher thermal diffusivity always retain higher quality for any processing temperature because they heat faster resulting in shorter process time. The maximum percent retentions increased from 67.47 to 70.08 and then to 72.31 as thermal diffusivities increased from 1.2 to 1.4 to 1.6, respectively. Although the thermal diffusivity had little influence on the resulting optimal temperature, the increase in optimal temperature when thermal diffusivity increases indicates that the faster heating rate of foods with high thermal diffusivity allows them to respond better for the benefit of the HTST processing to retain their qualities.

This increase in quality factor retention for food with higher thermal diffusivity was also true for all kinetic parameters regardless of container shapes and sizes, and processing temperatures. This is because the quality improvement is a benefit of the faster heat transfer rate in foods with higher thermal diffusivity which allowed the temperature distribution of the food to be uniform faster and reduce processing time for all processing temperature.

## Surface Heat Transfer Coefficient

The infinite heat transfer coefficient assumption is valid when food is packed in a metal container and heated with condensing steam. When food is packed in a non-metal material and/or heated with water or steam/air mixtures, a finite surface heat transfer coefficient is considered. In this study, h = 300 W/ m² K was used for finite h, the volume average quality retention was compared with those using the infinite h condition

The surface temperature of foods heated under the infinite surface heat transfer coefficient condition will be immediately raised to the medium temperature (Figure 4 14) High surface temperature is a driving force for increasing the rate of heat transfer throughout the container, resulting in a reduction of processing time. However the simulation result indicated that the volume integrated quality retention was insensitive to h value Changing h from finite to infinite changed less than ± 3% of percent retention regardless of shape of a container thermal diffusivity of the food and /or the kinetic data of food quality factors (Appendix E Table E 1-E 30)

Even though the effect of h is very small, the simulation result indicated that the quality factors with low Z value, processed at high temperature with infinite heat transfer coefficient, had lower percent retention than those processed with finite h (Figure 4 20) This is because with infinite h, the food surface temperature is high therefore the quality at the surface is mostly destroyed by heat before the target lethality is reached at the cold point. Since the volume at the surface constitutes a large proportion of a container as the overall volume retention was integrated a lower retention was obtained

Quality factors with high Z values had a higher retention with an infinite h than a finite h This is because their thermal destruction rate does not change much with higher temperature, and they benefit from the shorter processing time using infinite heat transfer coefficient It was also found that the optimum temperatures for foods using finite heat transfer coefficient were always slightly higher than those for infinite heat transfer cases

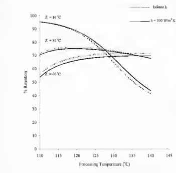


Figure 4 20 Effect of heat transfer coefficient on simulated retention of quality factors with $D_{ref}$ value = 200 minutes in conduction heated food having thermal diffusivity 1 4 x $10^{-7}$ $m^2/s$ packed in the conically shaped container #1

Container Geometry

The effect of different geometries of conical and elliptical containers on volume integrated quality retention is presented in Figure 4.21. The simulations were performed with foods with thermal diffusivity of $1.4 \times 10^{-7}$ m$^2$/s using infinite heat transfer coefficient, for a quality factor with $D_{ref}$ = 200 minutes and Z = 30 °C. The level of quality retention could be related to a total processing time required for each container to achieve equal lethality (Figure 4.15). The results indicate that as foods are packed in a container requiring less processing time, they retain higher quality at all processing temperature. This applies for all quality factors, in any processing condition within the scope of this study. Although the containers had very close optimum temperatures(Figure 4.21), the containers that require shorter processing time trend to have higher optimum temperatures.

Quality reduction in foods during thermal processing is unavoidable. However with a proper container, the quality loss could be reduced while ensuring product safety. The containers that allow rapid heat transfer and temperature uniformity lead to a shorter processing time. As a result, foods retain more quality/nutritional value, while using less energy. The developed heat transfer models are useful tools for evaluating quality retention, assisting the food processor in choosing the appropriate container geometry and optimum processing temperature, to achieve a better product quality.

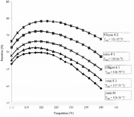


Figure 4.21 Effect of container geometry and processing temperature on the estimated retention of quality factor with Z value = 30 °C and $D_{ref}$ = 200 minutes in conduction heated food having thermal diffusivity 1.4 x $10^{-7}$ $m^2/s$, processed under heat transfer coefficient = 300 w / $m^2$ K

# CHAPTER 5
# CONCLUSION

1 The conduction heat transfer models, developed with the finite difference method based on energy balance approach for any given shape and size of a conical and a finite elliptical shaped container, can accurately predict the temperature distribution in response to either constant or variable surface temperature

2 The developed models can be further modified to predict the volume integrated retention of any quality factor following first order reaction kinetics, under the constraint of achieving a given target lethality

3 Quality retention for factors with low Z values are more sensitive to changes in process temperature away from the optimum temperature than those with high Z values The exact determination of the optimum temperature for the quality factors with Z less than 50 °C may not be necessary since only a small improvement in percent retention will be obtained

4 Quality retention increases when $D_{ref}$ value increases at all processing temperatures Although $D_{ref}$ value had little influence on optimum temperatures the quality factor with low $D_{ref}$ values with high Z value had a slightly lower optimal temperature

5. Foods with a higher thermal diffusivity require a shorter processing time and retain higher quality for any processing temperature. The optimal temperature slightly increases when thermal diffusivity increases from 1.2 to 1.6 x $10^{-7}$ $m^2/s$.

6. Even though foods processed under infinite heat transfer coefficient conditions require a shorter processing time than those processed under finite heat transfer coefficient conditions, the level of quality retention after processing under these conditions is hardly affected. Surface heat transfer coefficient had a small influence on the optimum processing temperature.

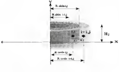
7. A container that allows rapid heat transfer results in foods retaining more quality/nutritional value at all processing temperature. Although the containers withing the scope of this study had very close optimum temperatures, the containers that require shorter processing time trend to have higher optimum temperatures. Heat transfer models provide the food processor an effective tool in choosing the appropriate container geometry to achieve a better product quality.

# APPENDIX A
# CALCULATION OF NODAL AREA AND VOLUME FOR A CONE FRUSTUM

## 1 Calculation for area in radial direction

### 1.1 $Ar_{i,j}$

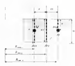
Equation to calculate cross section area of the interior nodes



$$Ar_{i,j} = \frac{1}{2}\left(2\pi H_j \frac{R_{node\ i+1,j} + R_{node\ i,j}}{2}\right)$$

## 1.2 $Ar_{avg,\,i,j}$

Equation to calculate average cross section area of the node adjacent to the node at the skin surface



$$Ar_{avg\,i,j} = \frac{\frac{Ar_1 + Ar_2}{2} X_1 + \frac{Ar_2 + Ar_3}{2} X_2}{X_1 + X_2}$$

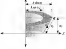
when

$$Ar_1 = \frac{1}{2}\left(2\pi\, R_{node\,i,j}\, H_1\right)$$

$$Ar_2 = \frac{1}{2}\left(2\pi\, R_{skin\,i,j}\, H_2\right)$$

$$Ar_3 = \frac{1}{2}\left(2\pi\, R_{node\,i+1,j}\, H_3\right)$$

### 1.3 $Ar_{slope\, i,j}$



Equation to calculate average cross section area of the node at the surface

$$S_{i,j} = \sqrt{H_{i,j}^{2} + (R_{skin\, i,j} - R_{skin\, i-1,j})^{2}}$$

$$Ar_{slope\, i,j} = \frac{1}{2}\pi\,(R_{skin\, i,j} + R_{skin\, i-1,j})\, S_{i,j}$$

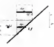
## 2. Calculation for nodal area in axial direction

### 2.1 $Ay_{i,j}$

Equation to calculate average cross section area of the interior nodes

$$Ay_{i,j} = \frac{1}{2}\pi\,(R_{skin\, i,j}^{2} - R_{skin\, i-1,j}^{2})$$

7.2 $Ay_{avg,\,i,j}$



Equation to calculate average cross section area of the node that adjacent to the node at the side surface

$$Ay_{avg\ i,j} = \frac{\frac{(Ay_1 + Ay_2)}{2}\,Y1 + Ay_2\,Y2}{Y1 + Y2}$$

when

$$Ay_1 = \frac{1}{2}\,\pi\,(R^2_{node\ i,j} - R^2_{skin\ ,\ i,j})$$

$$Ay_2 = \frac{1}{2}\,\pi\,(R^2_{skin\ i,j} - R^2_{skin\ ,\ i,j})$$

## 3. Calculations for nodal volume

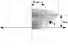
### 3.1 $V_{cyln\ i,j}$

Equation to calculate volume of the interior nodes of height $H_{i,j}$ is

$$V_{cyln\ i,j} = \frac{1}{2}\left(\pi R_{slice\ i,j}^{2} H_{i,j} - \pi R_{slice\ i-1,j}^{2} H_{i,j}\right)$$

### 3.2 $V_{triang\ i,j}$

Equation to calculate volume of the nodes at the surface is



$$V_{triang\ i,j} = \frac{1}{2}\left(\frac{1}{3}\pi H_{i,j}\left(R_{slice\ i,j} + R_{slice\ i-1,j} R_{slice\ i,j} + R_{slice\ i-1,j}\right)^{2} - \pi H_{i,j} R_{slice\ i-1,j}\right)$$

# APPENDIX B

## GRID GENERATION IN A FINITE ELLIPTICAL CYLINDER

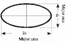


Figure B 1 An ellipse

An ellipse is given by the equation

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \tag{B-1}$$

where 'a' is one half the length of the major axis, 'b' is one half the length of the minor axis

A 2-dimensional finite difference model is developed for a finite elliptical cylinder with height 'h'. The finite elliptical cylinder was subdivided in to series of concentric elliptical ring stacked on top of each other with series of heat flow curves drawn perpendicularly with the ellipse perimeters. Due to symmetry only 1/4 of the finite elliptical cylinder is used to develop the energy balance equations Heat flows along its height and along the heat flows curves (Figure 3 13)

The input parameters for generating the grid for a finite elliptical cylinder are

- Dimensions including a, b and h
- Number of the concentric ellipses, number of the heat flow curves, and number of nodes in height

Grid generation involves determining of the perimeter of an ellipse in one quadrant (P) which can be calculated as

$$P = a\,E\,(\frac{\pi}{2}, e) \tag{B-2}$$

where e is an eccentricity of the ellipse

$$e = \sqrt{1 - \frac{b^2}{a^2}} \tag{B-3}$$

and E is an incomplete elliptic integral of the second kind calculate by using subroutine ELI2 (given at the end of this appendix)

Once the quadrant cord is found, the strategy for grid generation is as follows

1 Draw a series of heat flow curves

1 1 Locating of intersection points of the ellipse and the heat flow curves

The quadrant cord is divided by the number of heat flow curves to obtain equal arc-lengths By using bisection method and subroutine ELI2, the angle from the center (θ )that corresponds to the equal arc length can be found

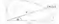


**Figure B-2** Location of the point on the perimeter

Form Figure B-2 the radius (r) can be written as

$$r = a\sqrt{\frac{1-e^2}{e^2\cos^2\theta-1}} \tag{B-4}$$

The coordinate at the perimeter is

$$x = r\cos\theta \tag{B-5}$$

$$y = r\sin\theta \tag{B-6}$$

1.2 Draw heat flow curves from the center to the intersection points

Once the intersection points on the perimeter of the ellipse are found the curves will be drawn form the center of the ellipse toward these points having the equation

$$y = c\,x^n \tag{B-7}$$

These curves are perpendicular with the ellipse perimeter at the intersection points. The product of the slope of the ellipse (SE) and the slope of the curve(SP) equals -1. The slope of the ellipse can be found by rearranging ellipse equation (B-1) as

$$y = \frac{b}{a}\sqrt{a^2 - x^2} \tag{B-8}$$

The slope at a point on the perimeter of an ellipse (SE) is the derivative of the equation B-8

$$SE = \frac{dy}{dx} = \frac{-b\,x}{a\sqrt{a^2 - x^2}} \tag{B-9}$$

or

$$SE = -\frac{x}{y}\,\frac{b^2}{a^2} \tag{B-10}$$

The slope of the heat line curve(SP) is the derivative of the equation B-7

$$SP = \frac{dy}{dx} = c\,n\,x^{n-1} \tag{B-11}$$

by setting

$$SP * SE = -1 \tag{B-12}$$

The power of the heat flow curve (n) and coefficient (c) could be solved as

$$n = \frac{a^2}{b^2} \tag{B-13}$$

The equation for desired x by the Newton method is

$$x_{n+1} = x_n - \frac{f(x)}{f'(x)} \qquad \text{(B–17)}$$

Once the x coordinates are found , the y coordinates could be obtained from equation B 8.

Calculation of the cross section nodal area.

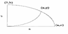


**Figure B-3** Illustrate cross section area

The area from (a,o) to the heat flow curve at of intersection point (x,y) as shown in figure B-3 could be calculated from

$$A=[\frac{ab}{2}\times \arcsin\frac{x}{a}]+[\frac{ab}{2}\ x\ \cos(\arcsin\frac{x}{a})]+[bc\frac{x^{n+1}}{n+1}] \qquad \text{(B–18)}$$

```
Sub ELI2(R, x, CK, a, b)
 ----------------------------------------------------
     PURPOSE
       COMPUTES THE GENERALIZED ELLIPTIC INTEGRAL OF SECOND KIND
     USAGE
       CALL ELI2(R,X,CK,A,B)

     DESCRIPTION OF PARAMETERS
       R    - RESULT VALUE
       X    - UPPER INTEGRATION BOUND (ARGUMENT OF ELLIPTIC
              INTEGRAL OF SECOND KIND)
       CK   - COMPLEMENTARY MODULUS
       A    - CONSTANT TERM IN NUMERATOR
       B    - QUADRATIC TERM IN NUMERATOR

     REMARKS
       MODULUS K = SQRT(1 -CK*CK)
       SPECIAL CASES OF THE GENERALIZED ELLIPTIC INTEGRAL OF
       SECOND KIND ARE
       F(ATAN(X),K) OBTAINED WITH A=1 , B=1
'  This is what we want     E(ATAN(X) K) OBTAINED WITH A=1_ B=CK*CK.
' k^2 + ck^2 = 1, and k^2 <= 1
'      B(ATAN(X) K) OBTAINED WITH A=1   B=0
'      D(ATAN(X) K) OBTAINED WITH A=0   B=1
'
'    SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
       NONE

     METHOD
     DEFINITION
     R=INTEGRAL((A+B*T*T)/(SQRT((1+T*T)*(1+(CK*T)**2))*(1+T*T))
        SUMMED OVER T FROM 0 TO X)
     EQUIVALENT IS THE DEFINITION
     R=INTEGRAL((A+(B-A)*(SIN(T))**2)/SQRT(1-(K*SIN(T))**2),
        SUMMED OVER T FROM 0 TO ATAN(X))
     EVALUATION
     LANDENS TRANSFORMATION IS USED FOR CALCULATION
     REFERENCE
     R. BULIRSCH  NUMERICAL CALCULATION OF ELLIPTIC INTEGRALS
AND
        ELLIPTIC FUNCTIONS
        HANDBOOK SERIES OF SPECIAL FUNCTIONS
        NUMERISCHE MATHEMATIK VOL. 7, 1965  PP  78 90

   - - - - - - - - - - - - -
   Dim C  D  AN  AA, ang, PIM  ISI  ARI  GEO  SGEO  AARI  AANG  PIMA
   Dim p
    TEST ARGUMENT
     If x = 0 Then
     R = 0#
     Exit Sub
     End If
    TEST MODULUS
   C = 0#
   D = 0 5
     If CK = 0 Then
     R = Sqr(1# + x * x)
     R = (a - b) * Abs(x) / R + b * Log(Abs(x) + R)
```

```
'  TEST SIGN OF ARGUMENT
      R = R + C * (a - b)
      If x < 0 Then R = -R
      Exit Sub
      End If
'  INITIALIZATION
    AN = (b + a) * 0 5
    AA = a
    R = b
    ang = Abs(1# / x)
    PIM = 0#
    ISI = 0
    ARI = 1#
    GEO = Abs(CK)
'  LANDEN TRANSFORMATION
Landen
    R = AA * GEO + R
    SGEO = ARI * GEO
    AA = AN
    AARI = ARI
'  ARITHMETIC MEAN
    ARI = GEO + ARI
   SUM OF SINE VALUES
    AN = (R / ARI + AA) * 0 5
    AANG = Abs(ang)
    ang = -SGEO / ang + ang
    PIMA = PIM
    If ang = 0 Then ang = -0 00000001 * AANG
      If ang <= 0 Then
```

```
        PIM = PIM + 3 1415927
        ISI = ISI + 1
        End If
    AANG = ARI * ARI + ang * ang
    p = D / Sqr(AANG)
    If ISI >= 4 Then ISI = ISI - 4
    If ISI >= 2 Then p = -p
    C = C + p
    D = D * (AARI   GEO) * 0 5 / ARI
        If Abs(AARI - GEO) > 0 0001 * AARI Then
        SGEO = Sqr(SGEO)
     GEOMETRIC MEAN
        GEO = SGEO + SGEO
        PIM = PIM + PIMA
        ISI = ISI + ISI
        GoTo Landen
        End If
     ACCURACY WAS SUFFICIENT
    R = (Atn(ARI / ang) + PIM) * AN / ARI
    C = C + D * ang / AANG
    R = R + C * (a - b)
    If x < 0 Then R = -R
End Sub
```

# APPENDIX C

## EXPERIMENTAL AND SIMULATED TEMPERATURE IN AN ACRYLIC MATERIAL, FINITE ELLIPTICAL CYLINDERS AND CONES

Table C-1 Experimental and simulated data for the finite elliptical cylinder #1 Experiment1

| Time | Temperature (°C) | | | | |
|---|---|---|---|---|---|
| (min) | Water | Exp 1 | Exp 2 | Sim 1 | Sim 2 |
| 0 | 24.91 | 24.3 | 24.36 | 24.42 | 24.42 |
| 1.94 | 79.12 | 26.35 | 24.06 | 26.74 | 24.49 |
| 2.91 | 79.51 | 32.23 | 25.09 | 31.05 | 25.12 |
| 3.89 | 79.03 | 37.21 | 26.45 | 35.94 | 26.78 |
| 4.86 | 79.58 | 42.69 | 29.97 | 40.63 | 29.36 |
| 5.83 | 79.69 | 46.96 | 33.53 | 44.86 | 32.52 |
| 6.8 | 79.38 | 50.17 | 36.93 | 48.62 | 35.93 |
| 7.77 | 79.61 | 53.58 | 40.87 | 51.95 | 39.38 |
| 8.74 | 79.66 | 56.21 | 44.3 | 54.9 | 42.73 |
| 9.71 | 79.7 | 58.51 | 47.63 | 57.51 | 45.91 |
| 10.69 | 79.19 | 60.11 | 50.04 | 59.84 | 48.88 |
| 11.66 | 79.17 | 61.98 | 52.62 | 61.9 | 51.63 |
| 12.63 | 79.65 | 64.19 | 55.51 | 63.72 | 54.16 |
| 13.6 | 79.63 | 65.55 | 57.76 | 65.35 | 56.46 |
| 14.57 | 79.42 | 66.68 | 59.54 | 66.81 | 58.56 |
| 15.54 | 79.41 | 67.82 | 61.4 | 68.13 | 60.48 |
| 16.51 | 79.64 | 69.02 | 63.27 | 69.31 | 62.23 |
| 17.49 | 79.62 | 70.13 | 64.79 | 70.37 | 63.82 |
| 18.46 | 79.22 | 70.52 | 65.77 | 71.31 | 65.27 |
| 19.43 | 79.22 | 71.31 | 67.07 | 72.14 | 66.59 |
| 20.4 | 79.67 | 72.36 | 68.48 | 72.88 | 67.78 |
| 21.37 | 2.95 | 72.87 | 69.57 | 73.56 | 68.86 |
| 22.34 | 1.67 | 72.86 | 70.65 | 72.69 | 69.83 |
| 23.32 | 1.54 | 67.67 | 71.3 | 68.03 | 70.28 |
| 24.29 | 1.82 | 60.35 | 70.75 | 61.72 | 69.36 |
| 25.26 | 0.93 | 52.78 | 67.9 | 55.34 | 66.92 |
| 26.23 | 1.28 | 46.79 | 64.03 | 49.44 | 63.39 |
| 27.2 | 2.31 | 41.92 | 60.14 | 44.16 | 59.25 |
| 28.17 | 3.92 | 37.29 | 55.36 | 39.55 | 54.9 |
| 29.14 | 5.56 | 33.56 | 50.8 | 35.58 | 50.57 |
| 30.12 | 4.32 | 30.03 | 45.89 | 32.21 | 46.46 |
| 31.09 | 4.11 | 27.68 | 41.96 | 29.27 | 42.64 |
| 32.06 | 5.63 | 25.13 | 38.08 | 26.65 | 39.14 |
| 33.03 | 7.33 | 22.61 | 34.24 | 24.36 | 35.95 |
| 34 | 9.3 | 20.92 | 31.19 | 22.44 | 33.06 |
| 34.97 | 11.66 | 19.93 | 28.89 | 20.91 | 30.47 |
| 35.94 | 13.63 | 19.08 | 26.49 | 19.76 | 28.2 |
| 36.92 | 15.45 | 18.46 | 24.4 | 18.96 | 26.26 |

note using h = 1300 W/$m^2$ K K = 0.195 W/m K Alpha = 1.12x $10^{-7}$ $m^2$/sec
This is the interporated data to show temperature for every minutes

Table C.2 Experimental and simulated data for the finite elliptical cylinder #1, experiment 2

| Time | Temperature (°C) | | | | |
|---|---|---|---|---|---|
| (min) | Water | Exp 1 | Exp 2 | Sim 1 | Sim 2 |
| 0 | 23.98 | 23.78 | 23.52 | 23.76 | 23.76 |
| 1.94 | 87.5 | 23.8 | 25.14 | 23.79 | 25.02 |
| 2.91 | 87.88 | 24.22 | 29.64 | 24.16 | 29.3 |
| 3.89 | 87.68 | 25.81 | 35.4 | 25.59 | 34.98 |
| 4.86 | 87.65 | 28.64 | 41.16 | 28.2 | 40.48 |
| 5.83 | 87.72 | 32.3 | 46.39 | 31.65 | 45.62 |
| 6.8 | 87.88 | 36.37 | 51.04 | 35.54 | 50.22 |
| 7.77 | 87.93 | 40.52 | 55.12 | 39.56 | 54.28 |
| 8.74 | 87.86 | 44.55 | 58.71 | 43.51 | 57.87 |
| 9.71 | 87.79 | 48.41 | 61.89 | 47.25 | 61.04 |
| 10.69 | 87.8 | 51.98 | 64.69 | 51.5 | 63.85 |
| 11.66 | 87.75 | 55.3 | 67.19 | 54.13 | 66.36 |
| 12.63 | 83.41 | 58.32 | 69.41 | 57.16 | 68.6 |
| 13.6 | 78.63 | 61.07 | 71.24 | 59.93 | 70.47 |
| 14.57 | 78.35 | 63.56 | 72.42 | 62.44 | 71.7 |
| 15.54 | 77.63 | 65.65 | 73.15 | 64.58 | 72.51 |
| 16.51 | 77.19 | 67.34 | 73.67 | 66.34 | 73.07 |
| 17.49 | 76.85 | 68.7 | 74.05 | 67.76 | 73.5 |
| 18.46 | 76.13 | 69.78 | 74.33 | 68.92 | 73.84 |
| 19.43 | 47.36 | 70.66 | 74.43 | 69.86 | 74 |
| 20.4 | 45.23 | 71.32 | 73.24 | 70.6 | 72.93 |
| 21.37 | 45.31 | 71.68 | 70.84 | 70.87 | 70.68 |
| 22.34 | 45.19 | 70.93 | 68.13 | 70.46 | 68.1 |
| 23.32 | 44.75 | 69.78 | 65.57 | 69.47 | 65.61 |
| 24.29 | 43.77 | 68.25 | 63.23 | 68.09 | 63.34 |
| 25.26 | 43.86 | 66.55 | 61.11 | 66.51 | 61.27 |
| 26.23 | 43.82 | 64.81 | 59.21 | 64.85 | 59.4 |
| 27.2 | 43.67 | 63.06 | 57.5 | 63.19 | 57.72 |
| 28.17 | 43.67 | 61.39 | 56 | 61.58 | 56.24 |
| 29.14 | 43.5 | 59.82 | 54.65 | 60.05 | 54.9 |
| 30.12 | 43.32 | 58.35 | 53.45 | 58.62 | 53.71 |
| 31.09 | 43.41 | 57 | 52.38 | 57.29 | 52.64 |
| 32.06 | 43.21 | 55.76 | 51.42 | 56.06 | 51.68 |
| 33.03 | 42.95 | 54.61 | 50.54 | 54.93 | 50.81 |
| 34 | 43.02 | 53.56 | 49.75 | 53.89 | 50.02 |

note using h = 1200 W/ $\text{m}^2$ K, K = 0.195 W/m K, Alpha = $1.12\times10^{-7}$ $\text{m}^2$/sec
This is the interpolated data to show temperature for every minutes

Table C-3 Experimental and simulated data for the finite elliptical cylinder #2
Experiment 1

| Time | Temperature (°C) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| (min) | Water | Exp1 | Exp 2 | Exp 3 | Exp 4 | Sim 1 | Sim 2 | Sim 3 | Sim 4 |
| 0.99 | 77.79 | 28.28 | 25.55 | 24.28 | 24.4 | 28.13 | 26.29 | 24.24 | 24.33 |
| 1.49 | 77.98 | 36.7 | 30.04 | 24.03 | 25.21 | 36.97 | 31.57 | 24.44 | 25.52 |
| 1.98 | 78.21 | 44.01 | 34.85 | 25.27 | 28 | 44.6 | 36.56 | 25.35 | 28 |
| 2.48 | 78.76 | 49.85 | 39.79 | 27.65 | 32.05 | 50.31 | 40.83 | 27.01 | 31.19 |
| 2.98 | 78.97 | 54.16 | 43.67 | 30.19 | 35.87 | 54.66 | 44.54 | 29.16 | 34.65 |
| 3.47 | 78.79 | 57.26 | 46.88 | 32.85 | 39.45 | 58.04 | 47.79 | 31.56 | 38.14 |
| 3.97 | 78.85 | 60.12 | 50.01 | 35.79 | 43.05 | 60.72 | 50.66 | 34.05 | 41.5 |
| 4.46 | 78.85 | 62.37 | 52.55 | 38.38 | 46.16 | 62.92 | 53.22 | 36.55 | 44.66 |
| 4.96 | 78.54 | 63.84 | 54.62 | 40.48 | 48.72 | 64.75 | 55.51 | 38.99 | 47.59 |
| 5.46 | 78.88 | 65.95 | 57.25 | 43.51 | 51.86 | 66.27 | 57.57 | 41.35 | 50.28 |
| 5.95 | 78.75 | 67.46 | 59.25 | 45.91 | 54.2 | 67.61 | 59.43 | 43.62 | 52.74 |
| 6.45 | 78.5 | 68.55 | 60.96 | 48.09 | 56.44 | 68.76 | 61.12 | 45.78 | 54.98 |
| 6.94 | 78.65 | 69.43 | 62.35 | 50.03 | 58.4 | 69.73 | 62.62 | 47.85 | 57.02 |
| 7.44 | 78.5 | 70.33 | 63.76 | 51.82 | 60.07 | 70.58 | 63.99 | 49.81 | 58.87 |
| 7.94 | 78.52 | 71.02 | 64.97 | 53.54 | 61.55 | 71.35 | 65.24 | 51.68 | 60.55 |
| 8.43 | 78.45 | 71.69 | 66.16 | 55.22 | 63.06 | 72.03 | 66.37 | 53.44 | 62.08 |
| 8.93 | 78.65 | 72.65 | 67.58 | 57.1 | 64.63 | 72.63 | 67.39 | 55.11 | 63.47 |
| 9.42 | 78.49 | 72.75 | 68.27 | 58.34 | 65.61 | 73.17 | 68.32 | 56.68 | 64.73 |
| 9.92 | 78.68 | 73.72 | 69.36 | 60.14 | 67.11 | 73.66 | 69.18 | 58.16 | 65.88 |
| 10.42 | 78.61 | 74.19 | 70.14 | 61.48 | 68.03 | 74.1 | 69.96 | 59.56 | 66.93 |
| 10.91 | 78.81 | 74.76 | 70.96 | 62.85 | 69 | 74.48 | 70.66 | 60.87 | 67.89 |
| 11.41 | 78.32 | 74.76 | 71.34 | 63.55 | 69.47 | 74.85 | 71.31 | 62.1 | 68.76 |
| 11.9 | 78.49 | 75.13 | 71.71 | 64.76 | 70.27 | 75.18 | 71.91 | 63.26 | 69.56 |
| 12.4 | 78.81 | 75.75 | 72.88 | 66.13 | 71.29 | 75.47 | 72.45 | 64.34 | 70.29 |
| 12.9 | 78.77 | 76.14 | 73.36 | 67.04 | 71.79 | 75.76 | 72.96 | 65.35 | 70.97 |
| 13.39 | 78.76 | 76.28 | 73.86 | 68.02 | 72.57 | 76.01 | 73.42 | 66.3 | 71.59 |
| 13.89 | 78.54 | 76.2 | 73.8 | 68.37 | 72.61 | 76.25 | 73.85 | 67.19 | 72.15 |
| 14.38 | 78.65 | 76.46 | 74.4 | 69.37 | 73.35 | 76.46 | 74.24 | 68.01 | 72.68 |
| 14.88 | 78.7 | 76.74 | 74.8 | 70.21 | 73.89 | 76.65 | 74.6 | 68.79 | 73.16 |
| 15.38 | 78.63 | 76.99 | 75.09 | 70.7 | 74.16 | 76.82 | 74.92 | 69.51 | 73.6 |
| 15.87 | 78.66 | 77.17 | 75.47 | 71.45 | 74.66 | 76.97 | 75.23 | 70.18 | 74 |
| 16.37 | 78.65 | 77.35 | 75.75 | 71.93 | 74.9 | 77.11 | 75.49 | 70.8 | 74.38 |
| 16.86 | 78.73 | 77.54 | 76.04 | 72.49 | 75.36 | 77.24 | 75.75 | 71.38 | 74.72 |
| 17.36 | 78.4 | 77.35 | 76.01 | 72.8 | 75.37 | 77.35 | 75.98 | 71.92 | 75.03 |
| 17.66 | 78.77 | 77.87 | 76.53 | 73.58 | 76.05 | 77.42 | 76.17 | 72.42 | 75.31 |
| 18.35 | 78.64 | 77.79 | 76.53 | 73.91 | 76.2 | 77.51 | 76.36 | 72.88 | 75.57 |
| 18.85 | 78.36 | 77.66 | 76.56 | 73.92 | 76.19 | 77.61 | 76.54 | 73.3 | 75.81 |
| 19.34 | 78.61 | 77.86 | 76.88 | 74.48 | 76.47 | 77.65 | 76.68 | 73.7 | 76.02 |
| 19.84 | 78.82 | 78.12 | 77.29 | 75.05 | 76.91 | 77.72 | 76.83 | 74.06 | 76.22 |
| 20.34 | 78.8 | 78.2 | 77.41 | 75.21 | 76.99 | 77.82 | 76.98 | 74.4 | 76.4 |

note Simulation using h = 400 W/ $m^2$ K, K = 0.26 W/m K Alpha = 1.49 x10 $^{-7}$ $m^2$/s
a = 4.64 cm, b = 3.13 cm Height = 2.54 cm
number of ellipse = 16 number of heat flow curve = 16 and node in height = 16
This is the interporated data to show temperature for every 30 second

Table C-4 Experimental and simulated data for the finite elliptical cylinder #2, Experiment 2

| Time | Temperature (°C) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| (min) | Water | Exp1 | Exp 2 | Exp 3 | Exp 4 | Sim 1 | Sim 2 | Sim 3 | Sim 4 |
| 1.48 | 79.73 | 38.02 | 30.81 | 24.52 | 25.81 | 38.21 | 32.54 | 24.87 | 26.17 |
| 1.98 | 79.8 | 45.17 | 35.67 | 25.78 | 28.88 | 45.32 | 37.24 | 25.94 | 28.71 |
| 2.48 | 80.31 | 50.86 | 40.31 | 28.18 | 32.77 | 51.13 | 41.58 | 27.63 | 31.89 |
| 2.98 | 80.39 | 55.43 | 44.65 | 30.86 | 36.55 | 55.63 | 45.38 | 29.8 | 35.38 |
| 3.47 | 80.28 | 58.51 | 47.85 | 33.46 | 40.21 | 59.11 | 48.7 | 32.22 | 38.81 |
| 3.97 | 80.44 | 61.56 | 51.15 | 36.31 | 44.03 | 61.87 | 51.64 | 34.75 | 42.32 |
| 4.46 | 80.44 | 63.68 | 53.73 | 38.98 | 47.2 | 64.13 | 54.26 | 37.29 | 45.54 |
| 4.96 | 80.56 | 65.61 | 56.19 | 41.65 | 50.04 | 66.02 | 56.61 | 39.77 | 48.53 |
| 5.46 | 80.4 | 67.24 | 58.28 | 44.11 | 52.8 | 67.63 | 58.73 | 42.18 | 51.28 |
| 5.95 | 80.36 | 68.62 | 60.13 | 46.4 | 55.08 | 68.88 | 60.64 | 44.48 | 53.79 |
| 6.45 | 80.11 | 69.55 | 61.66 | 48.48 | 57.1 | 70.16 | 62.36 | 46.71 | 56.09 |
| 6.94 | 80.34 | 70.91 | 63.5 | 50.87 | 59.37 | 71.12 | 63.88 | 48.82 | 58.17 |
| 7.44 | 80.48 | 71.87 | 65.28 | 52.81 | 61.28 | 72 | 65.28 | 50.82 | 60.06 |
| 7.94 | 80.33 | 72.51 | 66.27 | 54.49 | 62.54 | 72.81 | 66.56 | 52.72 | 61.77 |
| 8.43 | 80.48 | 73.45 | 67.67 | 56.4 | 64.44 | 73.55 | 67.74 | 54.52 | 63.34 |
| 8.93 | 80.01 | 73.26 | 67.98 | 57.35 | 65.13 | 74.21 | 68.82 | 56.23 | 64.76 |
| 9.42 | 80.68 | 74.54 | 69.71 | 58.54 | 66.84 | 74.76 | 69.78 | 57.84 | 66.07 |
| 9.92 | 80.63 | 74.77 | 70.38 | 60.85 | 67.7 | 75.34 | 70.7 | 58.36 | 67.26 |
| 10.42 | 2.01 | 75.43 | 71.3 | 62.28 | 68.86 | 75.68 | 71.51 | 60.8 | 68.36 |
| 10.91 | 1.11 | 68.43 | 66.08 | 63.3 | 69.16 | 66.74 | 67.06 | 62.14 | 68.87 |
| 11.41 | 0.69 | 56.99 | 63.38 | 64.12 | 68.45 | 53.88 | 59.73 | 62.88 | 67.46 |
| 11.9 | 0.49 | 47.72 | 57.79 | 63.89 | 65.65 | 43.96 | 53.29 | 62.37 | 64.2 |
| 12.4 | 0.74 | 40.27 | 52.42 | 62.43 | 61.34 | 36.58 | 47.86 | 60.76 | 60.07 |
| 12.9 | 0.54 | 34.54 | 47.53 | 59.97 | 57.03 | 31.07 | 43.19 | 58.48 | 55.62 |
| 13.39 | 0.51 | 30.08 | 43.29 | 57.48 | 52.8 | 26.78 | 39.11 | 55.85 | 51.18 |
| 13.89 | 0.77 | 26.32 | 38.41 | 54.54 | 48.37 | 23.36 | 35.5 | 53.08 | 46.82 |
| 14.38 | 0.78 | 23.27 | 35.88 | 51.81 | 44.43 | 20.57 | 32.3 | 50.3 | 42.93 |
| 14.88 | 0.56 | 20.38 | 32.46 | 48.68 | 40.44 | 18.26 | 29.43 | 47.54 | 39.24 |
| 15.38 | 0.66 | 18.46 | 29.64 | 46.08 | 37.03 | 16.3 | 26.85 | 44.87 | 35.87 |
| 15.87 | 0.4 | 16.31 | 26.75 | 43.06 | 33.57 | 14.59 | 24.51 | 42.28 | 32.78 |
| 16.37 | 0.8 | 14.85 | 24.85 | 40.88 | 31.02 | 13.13 | 22.41 | 39.8 | 29.99 |
| 16.86 | 0.58 | 13.23 | 22.3 | 38.15 | 28.18 | 11.89 | 20.53 | 37.41 | 27.44 |
| 17.36 | 0.72 | 11.88 | 20.36 | 35.65 | 26.08 | 10.79 | 18.82 | 35.14 | 25.13 |
| 17.86 | 0.86 | 11 | 18.81 | 33.32 | 23.86 | 9.82 | 17.27 | 32.87 | 23.04 |
| 18.35 | 0.42 | 9.77 | 17.28 | 31.17 | 21.61 | 8.87 | 15.87 | 30.8 | 21.14 |
| 18.85 | 1.62 | 9.21 | 15.95 | 29.14 | 20.09 | 8.19 | 14.58 | 28.94 | 19.42 |
| 19.34 | 75.56 | 12.71 | 15.94 | 27.29 | 18.75 | 10.47 | 14.86 | 27.09 | 17.88 |
| 19.84 | 76.77 | 24.61 | 21.16 | 25.18 | 18.56 | 22.09 | 20.99 | 25.48 | 17.64 |
| 20.34 | 77.74 | 34.71 | 27.06 | 25.3 | 20.88 | 32.96 | 27.31 | 24.84 | 19.52 |
| 20.83 | 78.28 | 42.26 | 32.56 | 26.15 | 24.67 | 41.18 | 32.74 | 25.42 | 22.68 |

Table C-4 --continued

| Time (min) | Temperature (°C) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Water | Exp 1 | Exp 2 | Exp 3 | Exp 4 | Sim 1 | Sim 2 | Sim 3 | Sim 4 |
| 21.33 | 78.67 | 47.7 | 36.94 | 27.95 | 28.74 | 47.35 | 37.4 | 26.87 | 26.47 |
| 21.83 | 79.23 | 52.47 | 41.45 | 30.47 | 33.11 | 52.1 | 41.47 | 28.85 | 30.46 |
| 22.32 | 79.26 | 55.7 | 44.8 | 32.71 | 36.82 | 55.88 | 45.07 | 31.1 | 34.41 |
| 22.82 | 79.98 | 58.93 | 48.33 | 35.56 | 40.66 | 58.97 | 48.29 | 33.45 | 38.19 |
| 23.31 | 80.37 | 61.21 | 51.12 | 37.79 | 44.32 | 61.57 | 51.21 | 35.84 | 41.74 |
| 23.81 | 80.54 | 63.72 | 53.87 | 40.44 | 47.48 | 63.83 | 53.87 | 38.21 | 45.05 |
| 24.31 | 81 | 65.63 | 56.29 | 42.82 | 50.42 | 65.8 | 56.3 | 40.54 | 48.1 |
| 24.8 | 81.69 | 67.6 | 58.81 | 45.38 | 53.23 | 67.53 | 58.52 | 42.82 | 50.92 |
| 25.3 | 81.81 | 68.85 | 60.49 | 47.27 | 55.4 | 69.11 | 60.58 | 45.03 | 53.52 |
| 25.79 | 82.4 | 70.66 | 62.67 | 49.74 | 57.84 | 70.53 | 62.47 | 47.18 | 55.91 |
| 26.29 | 82.72 | 71.79 | 64.15 | 51.7 | 59.76 | 71.79 | 64.21 | 49.25 | 58.12 |
| 26.79 | 82.13 | 72.89 | 66.03 | 53.62 | 61.82 | 72.94 | 65.81 | 51.26 | 60.16 |
| 27.28 | 81.68 | 73.78 | 67.27 | 55.31 | 63.51 | 73.88 | 67.23 | 53.19 | 62.04 |
| 27.78 | 81.28 | 74.66 | 68.71 | 57.14 | 65.1 | 74.6 | 68.46 | 55.04 | 63.74 |
| 28.27 | 80.71 | 75.06 | 69.66 | 58.7 | 66.33 | 75.17 | 69.54 | 56.8 | 65.28 |
| 28.77 | 80.19 | 75.46 | 70.6 | 60.25 | 67.82 | 75.6 | 70.46 | 58.45 | 66.65 |
| 29.27 | 79.93 | 75.96 | 71.38 | 61.98 | 68.92 | 75.91 | 71.26 | 59.99 | 67.86 |
| 29.76 | 72.67 | 75.77 | 71.9 | 63.26 | 69.84 | 75.9 | 71.83 | 61.43 | 68.93 |
| 30.26 | 73.01 | 75.23 | 72.29 | 64.65 | 70.74 | 75.01 | 71.79 | 62.74 | 69.77 |
| 30.75 | 73.67 | 74.29 | 72.18 | 65.69 | 71.2 | 74.2 | 71.7 | 63.88 | 70.32 |
| 31.25 | 73.96 | 74.06 | 72.2 | 66.56 | 71.42 | 73.74 | 71.72 | 64.83 | 70.68 |
| 31.75 | 74.6 | 73.69 | 72.24 | 67.21 | 71.53 | 73.56 | 71.83 | 65.62 | 70.95 |
| 32.24 | 75.05 | 73.66 | 72.26 | 67.71 | 71.69 | 73.54 | 71.99 | 66.33 | 71.18 |
| 32.74 | 75.51 | 73.9 | 72.56 | 68.21 | 72 | 73.66 | 72.21 | 66.97 | 71.39 |
| 33.23 | 76.1 | 74.13 | 72.79 | 68.75 | 72.12 | 73.86 | 72.47 | 67.56 | 71.62 |
| 33.73 | 76.65 | 74.43 | 72.95 | 69.41 | 72.29 | 74.13 | 72.76 | 68.13 | 71.86 |
| 34.23 | 76.99 | 74.52 | 73.13 | 69.8 | 72.56 | 74.45 | 73.08 | 68.67 | 72.13 |
| 34.72 | 77.33 | 74.81 | 73.38 | 69.96 | 72.76 | 74.78 | 73.41 | 69.2 | 72.42 |
| 35.22 | 77.7 | 74.97 | 73.6 | 70.42 | 72.91 | 75.12 | 73.75 | 69.72 | 72.73 |
| 35.71 | 78.38 | 75.57 | 74.18 | 70.99 | 73.35 | 75.48 | 74.1 | 70.22 | 73.05 |
| 36.21 | 78.77 | 75.86 | 74.47 | 71.36 | 73.72 | 75.86 | 74.47 | 70.7 | 73.39 |
| 36.71 | 78.65 | 75.84 | 74.48 | 71.43 | 73.54 | 76.24 | 74.84 | 71.18 | 73.74 |
| 37.2 | 79.24 | 76.35 | 75.05 | 72.31 | 74.44 | 76.62 | 75.21 | 71.65 | 74.1 |
| 37.7 | 79.6 | 76.98 | 75.59 | 72.83 | 74.85 | 76.97 | 75.58 | 72.11 | 74.47 |
| 38.19 | 79.61 | 77.21 | 75.57 | 73.01 | 74.93 | 77.29 | 75.92 | 72.56 | 74.83 |

note using h = 400 W/$m^2$ K, K = 0.26 W/m K, Alpha = 1.49 x $10^{-7}$ $m^2/s$

a = 4.64 cm, b = 3.13 cm, Height = 2.54 cm

number of ellipse = 16 number of heat flow curve = 16 and node in height = 16

This is the interpolated data to show temperature for every 30 second

Table C.5 Experimental and simulated data for the cone #1 Experiment 1

| Time (min) | Temperature (°C) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Water | Exp 1 | Exp 2 | Exp 3 | Exp 4 | Sim 1 | Sim 2 | Sim 3 | Sim 4 |
| 0 | 29.11 | 28.99 | 28.81 | 28.78 | 28.61 | 28.8 | 28.8 | 28.8 | 28.8 |
| 2 | 85.61 | 29.16 | 28.85 | 29.05 | 36.14 | 28.9 | 28.8 | 29.03 | 36.13 |
| 2.99 | 85.77 | 29.9 | 28.97 | 30.39 | 42.2 | 29.43 | 28.82 | 30.08 | 42.14 |
| 3.99 | 85.66 | 30.98 | 28.89 | 32.26 | 46.58 | 30.49 | 28.95 | 31.87 | 46.79 |
| 4.99 | 85.66 | 32.41 | 29.23 | 34.45 | 50.04 | 31.94 | 29.31 | 34.07 | 50.43 |
| 5.99 | 85.82 | 34.23 | 30.05 | 37.03 | 52.82 | 33.61 | 30 | 36.4 | 53.36 |
| 6.98 | 85.65 | 35.76 | 30.93 | 39.07 | 55.04 | 35.38 | 31.01 | 38.75 | 55.78 |
| 7.98 | 85.65 | 37.52 | 32.15 | 41.24 | 56.92 | 37.17 | 32.31 | 41.03 | 57.82 |
| 8.98 | 85.65 | 39.39 | 33.7 | 43.45 | 58.76 | 38.94 | 33.84 | 43.22 | 59.58 |
| 9.98 | 85.81 | 41.11 | 35.44 | 45.49 | 60.44 | 40.66 | 35.53 | 45.3 | 61.11 |
| 10.97 | 85.84 | 42.85 | 37.19 | 47.45 | 61.83 | 42.32 | 37.32 | 47.28 | 62.47 |
| 11.97 | 85.67 | 44.21 | 38.65 | 48.95 | 62.79 | 43.92 | 39.17 | 49.15 | 63.69 |
| 12.97 | 85.77 | 45.84 | 40.52 | 50.67 | 64.1 | 45.46 | 41.03 | 50.92 | 64.78 |
| 13.97 | 85.82 | 47.39 | 42.38 | 52.32 | 65.11 | 46.93 | 42.89 | 52.59 | 65.78 |
| 14.96 | 85.95 | 48.88 | 44.13 | 53.89 | 66.26 | 48.35 | 44.71 | 54.18 | 66.7 |
| 15.96 | 85.68 | 49.97 | 45.61 | 55.06 | 66.83 | 49.7 | 46.49 | 55.68 | 67.55 |
| 16.96 | 85.91 | 51.52 | 47.45 | 56.59 | 67.85 | 51 | 48.22 | 57.1 | 68.32 |
| 17.96 | 85.88 | 52.69 | 48.99 | 57.84 | 68.68 | 52.25 | 49.88 | 58.45 | 69.06 |
| 18.96 | 85.89 | 53.97 | 50.47 | 59.01 | 69.37 | 53.45 | 51.48 | 59.72 | 69.74 |
| 19.95 | 85.52 | 54.87 | 51.64 | 59.99 | 69.78 | 54.6 | 53.02 | 60.93 | 70.37 |
| 20.95 | 85.81 | 56.22 | 53.33 | 61.31 | 70.64 | 55.71 | 54.48 | 62.07 | 70.95 |
| 21.95 | 85.75 | 57.38 | 54.62 | 62.35 | 71.22 | 56.77 | 55.88 | 63.14 | 71.51 |
| 22.95 | 85.77 | 58.35 | 55.9 | 63.34 | 71.76 | 57.79 | 57.22 | 64.16 | 72.04 |
| 23.94 | 85.83 | 59.36 | 57.09 | 64.22 | 72.24 | 58.78 | 58.49 | 65.13 | 72.55 |
| 24.94 | 85.83 | 60.26 | 58.19 | 65.08 | 72.74 | 59.73 | 59.69 | 66.04 | 73.03 |
| 25.94 | 85.92 | 61.21 | 59.34 | 65.9 | 73.21 | 60.64 | 60.84 | 66.91 | 73.51 |
| 26.94 | 85.78 | 61.95 | 60.21 | 66.59 | 73.58 | 61.52 | 61.93 | 67.73 | 73.96 |
| 27.93 | 85.77 | 62.94 | 61.3 | 67.42 | 74.09 | 62.37 | 62.97 | 68.51 | 74.38 |
| 28.93 | 85.87 | 63.8 | 62.41 | 68.18 | 74.6 | 63.19 | 63.95 | 69.26 | 74.79 |
| 29.93 | 85.89 | 64.56 | 63.25 | 68.86 | 75.04 | 63.98 | 64.89 | 69.96 | 75.18 |
| 30.93 | 85.6 | 65.06 | 63.83 | 69.26 | 75.05 | 64.74 | 65.78 | 70.63 | 75.56 |
| 31.92 | 85.79 | 66.11 | 65.01 | 70.15 | 75.75 | 65.48 | 66.63 | 71.27 | 75.91 |
| 32.92 | 85.8 | 66.8 | 65.78 | 70.68 | 76.04 | 66.18 | 67.43 | 71.87 | 76.27 |
| 33.92 | 85.92 | 67.57 | 66.59 | 71.31 | 76.41 | 66.87 | 68.2 | 72.45 | 76.61 |
| 34.92 | 85.76 | 68.24 | 67.3 | 71.83 | 76.71 | 67.53 | 68.93 | 73 | 76.94 |
| 35.92 | 85.86 | 68.85 | 67.97 | 72.28 | 77 | 68.17 | 69.62 | 73.52 | 77.25 |
| 36.91 | 85.77 | 69.39 | 68.73 | 72.83 | 77.37 | 68.79 | 70.28 | 74.02 | 77.55 |
| 37.91 | 85.85 | 69.97 | 69.34 | 73.32 | 77.59 | 69.38 | 70.91 | 74.49 | 77.84 |
| 38.91 | 85.62 | 70.34 | 69.82 | 73.6 | 77.66 | 69.96 | 71.51 | 74.95 | 78.12 |
| 39.91 | 85.86 | 71.12 | 70.54 | 74.21 | 78.23 | 70.51 | 72.09 | 75.38 | 78.37 |
| 40.9 | 85.79 | 71.55 | 71.09 | 74.6 | 78.42 | 71.04 | 72.64 | 75.79 | 78.63 |
| 41.9 | 85.85 | 72.03 | 71.58 | 74.91 | 78.58 | 71.56 | 73.16 | 76.18 | 78.89 |
| 42.9 | 85.6 | 72.32 | 71.84 | 75.12 | 78.7 | 72.06 | 73.66 | 76.56 | 79.14 |
| 43.9 | 85.81 | 73.08 | 72.59 | 75.67 | 79.15 | 72.54 | 74.13 | 76.92 | 79.37 |

Table C-5 (cont.)

| Time | Temperature (°C) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| (min) | Water T | Exp 1 | Exp 2 | Exp 3 | Exp 4 | Sim 1 | Sim 2 | Sim 3 | Sim 4 |
| 44.89 | 85.82 | 73.44 | 73.09 | 76.06 | 79.35 | 73 | 74.59 | 77.26 | 79.59 |
| 45.89 | 85.72 | 73.83 | 73.41 | 76.35 | 79.45 | 73.45 | 75.02 | 77.59 | 79.81 |
| 46.89 | 85.76 | 74.3 | 73.92 | 76.7 | 79.74 | 73.88 | 75.44 | 77.91 | 80.02 |
| 47.89 | 85.89 | 74.7 | 74.36 | 77.09 | 79.93 | 74.3 | 75.84 | 78.21 | 80.21 |
| 48.88 | 23.61 | 75.25 | 75.03 | 77.54 | 77.5 | 74.69 | 76.22 | 78.46 | 76.68 |
| 49.88 | 23.83 | 75.36 | 75.37 | 77.42 | 70.78 | 74.81 | 76.58 | 78.15 | 69.56 |
| 50.88 | 23.73 | 74.94 | 75.54 | 76.23 | 65.1 | 74.35 | 76.88 | 76.88 | 63.87 |
| 51.88 | 24.12 | 74.36 | 76.11 | 74.7 | 60.93 | 73.35 | 76.98 | 74.94 | 59.52 |
| 52.88 | 24.17 | 73.29 | 76.18 | 72.64 | 57.62 | 71.99 | 76.75 | 72.7 | 56.12 |
| 53.87 | 24.07 | 71.65 | 75.76 | 70.25 | 54.69 | 70.45 | 76.16 | 70.37 | 53.38 |
| 54.87 | 24.24 | 70.18 | 75.18 | 68.19 | 52.45 | 68.83 | 75.21 | 68.08 | 51.13 |
| 55.87 | 24.31 | 68.5 | 74.18 | 65.97 | 50.44 | 67.21 | 73.96 | 65.86 | 49.23 |
| 56.87 | 24.28 | 66.9 | 72.98 | 63.78 | 48.59 | 65.61 | 72.48 | 63.75 | 47.61 |
| 57.86 | 24.16 | 65.21 | 71.36 | 61.71 | 46.99 | 64.07 | 70.85 | 61.74 | 46.2 |
| 58.86 | 24.36 | 63.78 | 69.95 | 60 | 45.78 | 62.58 | 69.13 | 59.85 | 44.97 |
| 59.86 | 24.24 | 62.19 | 68.27 | 58.07 | 44.34 | 61.16 | 67.35 | 58.06 | 43.88 |
| 60.86 | 24.38 | 60.81 | 66.64 | 56.51 | 43.4 | 59.79 | 65.57 | 56.38 | 42.88 |
| 61.85 | 24.52 | 59.54 | 64.94 | 54.97 | 42.41 | 58.49 | 63.79 | 54.79 | 42 |
| 62.85 | 24.38 | 58.08 | 63.08 | 53.29 | 41.31 | 57.24 | 62.05 | 53.29 | 41.2 |
| 63.85 | 24.5 | 56.81 | 61.48 | 52.06 | 40.51 | 56.05 | 60.36 | 51.87 | 40.46 |
| 64.85 | 24.35 | 55.46 | 59.8 | 50.64 | 39.59 | 54.91 | 58.72 | 50.54 | 39.78 |
| 65.84 | 24.54 | 54.32 | 58.24 | 49.58 | 38.96 | 53.81 | 57.15 | 49.28 | 39.14 |
| 66.84 | 24.3 | 52.97 | 56.52 | 48.06 | 38.13 | 52.77 | 55.64 | 48.1 | 38.55 |
| 67.84 | 24.6 | 52.14 | 55.29 | 47.19 | 37.86 | 51.76 | 54.2 | 46.98 | 38 |
| 68.84 | 24.56 | 51 | 53.85 | 46.05 | 37.01 | 50.79 | 52.83 | 45.92 | 37.49 |
| 69.84 | 24.55 | 49.85 | 52.44 | 44.99 | 36.29 | 49.87 | 51.53 | 44.92 | 37.01 |
| 70.83 | 24.64 | 48.98 | 51.26 | 44.08 | 35.93 | 48.98 | 50.29 | 43.98 | 36.54 |
| 71.83 | 24.64 | 47.96 | 49.89 | 42.99 | 35.29 | 48.12 | 49.11 | 43.09 | 36.11 |
| 72.83 | 24.78 | 47.07 | 48.89 | 42.26 | 34.95 | 47.29 | 47.99 | 42.25 | 35.7 |
| 73.83 | 24.53 | 45.95 | 47.56 | 41.16 | 34.18 | 46.5 | 46.93 | 41.46 | 35.31 |
| 74.82 | 24.74 | 45.29 | 46.62 | 40.5 | 33.94 | 45.74 | 45.93 | 40.71 | 34.93 |
| 75.82 | 24.7 | 44.34 | 45.62 | 39.86 | 33.5 | 45 | 44.98 | 40 | 34.57 |
| 76.82 | 24.79 | 43.48 | 44.6 | 39.06 | 33.04 | 44.29 | 44.07 | 39.33 | 34.23 |
| 77.82 | 24.86 | 42.76 | 43.68 | 38.45 | 32.77 | 43.61 | 43.22 | 38.69 | 33.91 |
| 78.81 | 24.88 | 42.01 | 42.86 | 37.44 | 32.45 | 42.95 | 42.41 | 38.09 | 33.59 |
| 79.81 | 24.89 | 41.24 | 41.95 | 37.09 | 32 | 42.32 | 41.64 | 37.52 | 33.29 |

note using h = 110 W/m$^2$ K, K = 0.19 W/m K, Alpha = 1.09 x10$^{-7}$ m$^2$/s
top radius = 5.08 cm, small radius = 0.005 cm, height = 12.7 cm
number of node in small radius = 1 and number of node in height = 20
This is the interpolated data to show temperature for every minutes

Table C-6 Experimental and simulated data for the cone # 1, Experiment 2

| Time (min) | Temperature (°C) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Water | Exp1 | Exp 2 | Exp 3 | Exp 4 | Sim 1 | Sim 2 | Sim 3 | Sim 4 |
| 0 | 25.34 | 25.16 | 25.13 | 25.08 | 24.7 | 25.02 | 25.02 | 25.02 | 25.02 |
| 1.99 | 86.81 | 25.05 | 24.74 | 25.26 | 31.11 | 25.11 | 25.02 | 25.23 | 31.20 |
| 2.99 | 87.15 | 25.88 | 24.85 | 26.84 | 39.21 | 25.57 | 25.04 | 26.15 | 38.53 |
| 3.99 | 87.2 | 27.27 | 25.01 | 29.15 | 45.26 | 26.63 | 25.15 | 27.99 | 44.49 |
| 4.98 | 87.37 | 29.24 | 25.55 | 31.93 | 49.89 | 28.21 | 25.5 | 30.47 | 49.04 |
| 5.98 | 87.34 | 31.16 | 26.57 | 34.51 | 53.41 | 30.13 | 26.19 | 33.2 | 52.62 |
| 6.98 | 87.28 | 33.1 | 27.76 | 37.07 | 56.24 | 32.19 | 27.27 | 35.97 | 55.5 |
| 7.97 | 86.56 | 34.84 | 29.02 | 39.32 | 58.54 | 34.3 | 28.71 | 38.67 | 57.85 |
| 8.97 | 79.49 | 37.05 | 31.07 | 41.94 | 60.01 | 36.37 | 30.43 | 41.23 | 59.51 |
| 9.97 | 80.58 | 39.05 | 33.02 | 44.16 | 60.68 | 38.36 | 32.36 | 43.61 | 60.32 |
| 10.96 | 81.45 | 40.67 | 34.93 | 45.94 | 61.52 | 40.2 | 34.42 | 45.72 | 61.18 |
| 11.96 | 82.3 | 42.17 | 36.79 | 47.48 | 62.51 | 41.89 | 36.53 | 47.61 | 62.15 |
| 12.96 | 81.6 | 43.68 | 38.75 | 49 | 63.56 | 43.47 | 38.62 | 49.37 | 63.13 |
| 13.95 | 67.39 | 45.37 | 40.92 | 50.8 | 64.4 | 44.96 | 40.66 | 51.02 | 63.43 |
| 14.95 | 68 | 46.66 | 42.76 | 52.27 | 63.52 | 46.34 | 42.63 | 52.48 | 62.45 |
| 15.95 | 68.95 | 47.84 | 44.26 | 53.27 | 62.52 | 47.52 | 44.5 | 53.61 | 61.74 |
| 16.94 | 70.47 | 49.01 | 46.13 | 54.3 | 62.11 | 48.5 | 46.25 | 54.48 | 61.49 |
| 17.94 | 71.68 | 49.98 | 47.6 | 55.08 | 62.11 | 49.34 | 47.85 | 55.22 | 61.62 |
| 18.94 | 72.48 | 50.59 | 48.71 | 55.52 | 62.38 | 50.12 | 49.27 | 55.9 | 61.96 |
| 19.93 | 73.69 | 51.44 | 50.1 | 56.25 | 62.64 | 50.86 | 50.54 | 56.57 | 62.44 |
| 20.93 | 74.94 | 52.4 | 51.38 | 57.02 | 63.42 | 51.59 | 51.67 | 57.26 | 63.04 |
| 21.93 | 76.01 | 53.18 | 52.36 | 57.68 | 64.09 | 52.33 | 52.7 | 57.96 | 63.74 |
| 22.92 | 77.04 | 53.96 | 53.29 | 58.29 | 64.83 | 53.09 | 53.64 | 58.69 | 64.49 |
| 23.92 | 77.83 | 54.46 | 53.99 | 58.77 | 65.61 | 53.86 | 54.53 | 59.43 | 65.28 |
| 24.92 | 78.86 | 55.28 | 54.86 | 59.54 | 66.4 | 54.65 | 55.38 | 60.2 | 66.07 |
| 25.91 | 79.94 | 56.15 | 55.7 | 60.3 | 67.23 | 55.45 | 56.21 | 60.98 | 66.89 |
| 26.91 | 60.72 | 56.8 | 56.4 | 60.93 | 68.07 | 56.26 | 57.02 | 61.77 | 67.74 |
| 27.91 | 83.47 | 57.48 | 57.02 | 61.55 | 68.91 | 57.08 | 57.83 | 62.57 | 68.58 |
| 28.9 | 82.45 | 58.35 | 57.8 | 62.38 | 69.74 | 57.91 | 58.63 | 63.37 | 69.41 |
| 29.9 | 83.45 | 59.32 | 58.69 | 63.33 | 70.58 | 58.74 | 59.43 | 64.19 | 70.25 |
| 30.9 | 64.08 | 60.02 | 59.36 | 63.93 | 71.44 | 59.58 | 60.23 | 65 | 71.11 |
| 31.89 | 64.92 | 60.87 | 60.16 | 64.84 | 72.28 | 60.43 | 61.04 | 65.82 | 71.94 |
| 32.89 | 85.87 | 61.83 | 61.09 | 65.8 | 73.1 | 61.27 | 61.84 | 66.64 | 72.78 |
| 33.89 | 86.57 | 62.62 | 61.81 | 66.59 | 73.92 | 62.12 | 62.66 | 67.47 | 73.62 |
| 34.88 | 86.95 | 63.35 | 62.48 | 67.31 | 74.71 | 62.96 | 63.47 | 68.29 | 74.43 |
| 35.88 | 87.1 | 64.17 | 63.29 | 68.1 | 75.46 | 63.81 | 64.29 | 69.11 | 75.18 |
| 36.88 | 87.23 | 64.95 | 64.06 | 68.87 | 76.13 | 64.65 | 65.11 | 69.92 | 75.85 |
| 37.87 | 87.26 | 65.76 | 64.88 | 69.61 | 76.72 | 65.47 | 65.93 | 70.71 | 76.45 |

Table C-6 --continued

| Time (min) | Temperature (°C) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Water | Exp 1 | Exp 2 | Exp 3 | Exp 4 | Sim 1 | Sim 2 | Sim 3 | Sim 4 |
| 38.87 | 87.11 | 66.37 | 65.52 | 70.21 | 77.24 | 66.28 | 66.74 | 71.47 | 76.99 |
| 39.87 | 87.11 | 67.16 | 66.25 | 70.92 | 77.7 | 67.06 | 67.55 | 72.19 | 77.46 |
| 40.86 | 87.18 | 68.02 | 67.12 | 71.7 | 78.12 | 67.81 | 68.35 | 72.88 | 77.89 |
| 41.86 | 87.13 | 68.63 | 67.83 | 72.27 | 78.53 | 68.54 | 69.13 | 73.53 | 78.29 |
| 42.86 | 87.15 | 69.34 | 68.58 | 72.91 | 78.9 | 69.23 | 69.88 | 74.15 | 78.67 |
| 43.85 | 86.96 | 69.88 | 69.15 | 73.33 | 79.24 | 69.9 | 70.62 | 74.73 | 79.01 |
| 44.85 | 87.03 | 70.64 | 70.05 | 74.03 | 79.54 | 70.54 | 71.33 | 75.29 | 79.32 |
| 45.85 | 87.19 | 71.29 | 70.82 | 74.65 | 79.84 | 71.16 | 72 | 75.81 | 79.62 |
| 46.84 | 87.16 | 71.85 | 71.43 | 75.11 | 80.13 | 71.75 | 72.66 | 76.3 | 79.93 |
| 47.84 | 87.16 | 72.42 | 71.98 | 75.56 | 80.41 | 72.32 | 73.28 | 76.78 | 80.22 |
| 48.84 | 87.24 | 72.98 | 72.59 | 76.09 | 80.69 | 72.86 | 73.87 | 77.23 | 80.49 |

note using h = 110 W/ $m^2$ K, K = 0.19 W/m K, Alpha = 1.09 x$10^{-7}$ $m^2$/sec
top radius = 5.08 cm small radius = 0.005 cm, height = 12.7 cm
number of node in small radius = 1 and number of node in height = 20
This is the interporated data to show temperature for every minutes

Table C-7 Experiment and simulation data for the case # 2, Experiment 1

| Time (min | Temperature (°C) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Water | Exp 1 | Exp 2 | Exp 3 | Sim 1 | Sim 2 | Sim 3 |
| 0 | 24.81 | 24.76 | 24.72 | 24.74 | 24.74 | 24.74 | 24.74 |
| 2 | 86.2 | 24.97 | 25 | 25.33 | 24.74 | 24.75 | 24.89 |
| 3 | 86.21 | 24.83 | 24.96 | 26.05 | 24.8 | 24.82 | 25.9 |
| 4 | 86.21 | 25.29 | 24.96 | 27.94 | 25.08 | 24.97 | 27.8 |
| 5 | 86.21 | 26.17 | 25.57 | 30.03 | 25.69 | 25.23 | 30.14 |
| 6 | 86.17 | 27.1 | 25.72 | 32.08 | 26.63 | 25.62 | 32.62 |
| 7 | 85.9 | 28.05 | 26.02 | 33.92 | 27.84 | 26.11 | 35.08 |
| 8 | 86.21 | 29.4 | 26.63 | 36.6 | 29.25 | 26.72 | 37.45 |
| 9 | 85.86 | 30.95 | 26.92 | 38.48 | 30.78 | 27.42 | 39.69 |
| 10 | 86.21 | 32.55 | 28.8 | 40.46 | 32.39 | 28.22 | 41.8 |
| 11 | 86.08 | 34.05 | 28.52 | 42.12 | 34.04 | 29.1 | 43.79 |
| 12 | 86.3 | 35.68 | 29.75 | 44.22 | 35.7 | 30.06 | 45.65 |
| 13 | 86.4 | 37.68 | 30.91 | 45.84 | 37.36 | 31.08 | 47.39 |
| 14 | 86.07 | 38.78 | 31.78 | 47.16 | 38.99 | 32.17 | 49.04 |
| 15 | 86.29 | 40.57 | 33.19 | 48.94 | 40.6 | 33.31 | 50.59 |
| 15.99 | 86.2 | 41.94 | 34.31 | 50.39 | 42.17 | 34.49 | 52.05 |
| 16.99 | 86.24 | 43.41 | 35.74 | 51.56 | 43.7 | 35.7 | 53.43 |
| 17.99 | 86.22 | 44.9 | 37.06 | 53.13 | 45.18 | 36.94 | 54.73 |
| 18.99 | 86.46 | 46.42 | 38.63 | 54.62 | 46.62 | 38.2 | 55.97 |
| 19.99 | 86.29 | 47.65 | 39.95 | 55.55 | 48.01 | 39.46 | 57.15 |
| 20.99 | 86.27 | 49.01 | 41.12 | 56.75 | 49.35 | 40.74 | 58.27 |
| 21.99 | 86.41 | 50.49 | 42.78 | 57.76 | 50.66 | 42.01 | 59.34 |
| 22.99 | 86.39 | 51.64 | 43.89 | 58.96 | 51.91 | 43.28 | 60.36 |
| 23.99 | 86.61 | 52.88 | 45.24 | 60.12 | 53.13 | 44.54 | 61.33 |
| 24.99 | 86.56 | 54.22 | 46.54 | 61.13 | 54.3 | 45.79 | 62.26 |
| 25.99 | 86.63 | 55.2 | 47.93 | 61.88 | 55.43 | 47.02 | 63.16 |
| 26.99 | 86.49 | 56.41 | 49.03 | 63.05 | 56.52 | 48.23 | 64.02 |
| 27.99 | 86.43 | 57.28 | 50.33 | 63.68 | 57.57 | 49.43 | 64.84 |
| 28.99 | 86.67 | 58.36 | 51.66 | 64.71 | 58.59 | 50.6 | 65.63 |
| 29.99 | 86.51 | 59.19 | 52.64 | 65.41 | 59.57 | 51.75 | 66.39 |
| 30.99 | 86.68 | 60.23 | 53.77 | 66.19 | 60.52 | 52.87 | 67.12 |
| 31.99 | 86.67 | 61.41 | 54.92 | 67.08 | 61.44 | 53.97 | 67.82 |
| 32.99 | 86.66 | 62.25 | 55.98 | 67.72 | 62.32 | 55.04 | 68.49 |
| 33.99 | 86.48 | 62.89 | 56.93 | 68.56 | 63.17 | 56.08 | 69.14 |
| 34.99 | 86.47 | 63.76 | 58.02 | 69.09 | 63.99 | 57.1 | 69.76 |
| 35.99 | 86.44 | 64.68 | 58.96 | 69.78 | 64.79 | 58.08 | 70.36 |
| 36.99 | 86.31 | 65.48 | 60.02 | 70.49 | 65.55 | 59.04 | 70.94 |
| 37.99 | 86.39 | 66.11 | 60.99 | 70.88 | 66.29 | 59.98 | 71.49 |

Table C 7 --continued

| Time (min) | Temperature (°C) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Water | Exp 1 | Exp 2 | Exp 3 | Sim 1 | Sim 2 | Sim 3 |
| 38.99 | 86.34 | 66.82 | 61.79 | 71.29 | 67 | 60.88 | 72.02 |
| 39.99 | 86.45 | 67.67 | 62.81 | 72.16 | 67.69 | 61.76 | 72.53 |
| 40.99 | 86.41 | 68.39 | 63.54 | 72.41 | 68.35 | 62.61 | 73.02 |
| 41.99 | 86.37 | 68.94 | 64.25 | 73.03 | 68.98 | 63.43 | 73.49 |
| 42.99 | 86.3 | 69.27 | 64.95 | 73.39 | 69.6 | 64.23 | 73.94 |
| 43.99 | 86.3 | 70 | 65.69 | 74.02 | 70.19 | 65 | 74.38 |
| 44.99 | 86.36 | 70.68 | 66.53 | 74.4 | 70.76 | 65.75 | 74.81 |
| 45.99 | 86.14 | 71.22 | 67.17 | 74.84 | 71.31 | 66.47 | 75.22 |
| 46.98 | 86.32 | 71.51 | 67.88 | 75.23 | 71.84 | 67.17 | 75.61 |
| 47.98 | 86.44 | 72.33 | 68.62 | 75.63 | 72.35 | 67.84 | 75.99 |
| 48.98 | 86.22 | 72.69 | 69.24 | 75.99 | 72.84 | 68.49 | 76.36 |
| 49.98 | 86.25 | 73.13 | 69.77 | 76.22 | 73.32 | 69.12 | 76.71 |

Note Using h = 150 W/ $m^2$ K, K = 0.19 W/m K, Alpha = 1.09 x$10^{-7}$ $m^2$/sec
top radius = 5.08 cm, small radius = 2.54 cm, height = 7.62 cm
number of node in small radius = 15 and number of node in height = 15
This is the interporated data to show temperature for every minutes

Table C-8 Experimental and simulated data for the case # 2 Experiment 2

| Time | Temperature (°C) | | | | | | |
|---|---|---|---|---|---|---|---|
| (min) | Water | Exp 1 | Exp 2 | Exp 3 | Sim 1 | Sim 2 | Sim 3 |
| 0 | 22.13 | 21.07 | 21.63 | 21.55 | 21.42 | 21.42 | 21.42 |
| 2 | 23.3 | 21.88 | 21.53 | 21.89 | 21.42 | 21.42 | 21.43 |
| 2.99 | 81.75 | 22 | 21.88 | 21.9 | 21.42 | 21.42 | 21.46 |
| 3.99 | 82.64 | 21.89 | 21.89 | 22.12 | 21.43 | 21.43 | 21.72 |
| 4.99 | 83.32 | 21.96 | 22.05 | 23.23 | 21.53 | 21.49 | 22.77 |
| 5.99 | 83.91 | 22.26 | 22.08 | 25.14 | 21.85 | 21.63 | 24.59 |
| 6.98 | 83.92 | 22.89 | 22.37 | 27.47 | 22.49 | 21.87 | 26.83 |
| 7.98 | 83.81 | 23.84 | 22.79 | 29.9 | 23.44 | 22.22 | 29.21 |
| 8.98 | 83.54 | 25.05 | 23.34 | 32.35 | 24.64 | 22.68 | 31.59 |
| 9.98 | 83.35 | 26.43 | 24.01 | 34.67 | 26.04 | 23.26 | 33.91 |
| 10.98 | 82.77 | 27.96 | 24.8 | 36.89 | 27.56 | 23.93 | 36.11 |
| 11.97 | 75.47 | 29.55 | 25.66 | 38.97 | 29.16 | 24.7 | 38.18 |
| 12.97 | 75.15 | 31.18 | 26.61 | 40.88 | 30.79 | 25.55 | 40.1 |
| 13.97 | 75.85 | 32.82 | 27.62 | 42.58 | 32.43 | 26.48 | 41.8 |
| 14.97 | 76.58 | 34.41 | 28.68 | 44.05 | 34.03 | 27.46 | 43.29 |
| 15.97 | 77.3 | 35.96 | 29.77 | 45.38 | 35.57 | 28.49 | 44.64 |
| 16.96 | 77.95 | 37.42 | 30.89 | 46.62 | 37.03 | 29.56 | 45.9 |
| 17.96 | 78.69 | 38.81 | 32.02 | 47.8 | 38.44 | 30.66 | 47.1 |
| 18.96 | 79.42 | 40.16 | 33.17 | 48.94 | 39.79 | 31.79 | 48.27 |
| 19.96 | 80.12 | 41.46 | 34.32 | 50.06 | 41.1 | 32.93 | 49.4 |
| 20.95 | 75.55 | 42.73 | 35.5 | 51.16 | 42.36 | 34.09 | 50.51 |
| 21.95 | 73.02 | 43.95 | 36.67 | 52.21 | 43.6 | 35.25 | 51.58 |
| 22.95 | 73.69 | 45.14 | 37.85 | 53.17 | 44.8 | 36.42 | 52.55 |
| 23.95 | 74.05 | 46.29 | 39.02 | 54.01 | 45.95 | 37.58 | 53.39 |
| 24.95 | 74.11 | 47.38 | 40.15 | 54.73 | 47.04 | 38.73 | 54.14 |
| 25.94 | 74.9 | 48.4 | 41.29 | 55.41 | 48.06 | 39.86 | 54.84 |
| 26.94 | 75.14 | 49.37 | 42.38 | 56.05 | 49.02 | 40.97 | 55.51 |
| 27.94 | 75.57 | 50.27 | 43.44 | 56.68 | 49.94 | 42.06 | 56.16 |
| 28.94 | 75.82 | 51.15 | 44.49 | 57.32 | 50.81 | 43.12 | 56.8 |
| 29.94 | 76.12 | 51.98 | 45.5 | 57.93 | 51.65 | 44.16 | 57.43 |
| 30.93 | 76.74 | 52.79 | 46.49 | 58.56 | 52.46 | 45.17 | 58.06 |
| 31.93 | 77.23 | 53.57 | 47.46 | 59.17 | 53.25 | 46.16 | 58.68 |
| 32.93 | 77.41 | 54.34 | 48.4 | 59.78 | 54.02 | 47.12 | 59.3 |
| 33.93 | 77.86 | 55.08 | 49.32 | 60.39 | 54.76 | 48.07 | 59.92 |
| 34.92 | 78.44 | 55.81 | 50.22 | 60.99 | 55.5 | 48.98 | 60.53 |
| 35.92 | 78.47 | 56.52 | 51.09 | 61.59 | 56.21 | 49.88 | 61.14 |
| 36.92 | 79.06 | 57.22 | 51.95 | 62.19 | 56.92 | 50.76 | 61.74 |
| 37.92 | 79.49 | 57.91 | 52.78 | 62.79 | 57.61 | 51.61 | 62.34 |
| 38.92 | 79.68 | 58.59 | 53.59 | 63.36 | 58.29 | 52.44 | 62.93 |
| 39.91 | 79.7 | 59.25 | 54.39 | 63.94 | 58.96 | 53.26 | 63.52 |

Table C 8 --continued

| Time (min) | Temperature (°C) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Water | Exp 1 | Exp 2 | Exp 3 | Sim 1 | Sim 2 | Sim 3 |
| 40.91 | 80.05 | 59.91 | 55.17 | 64.52 | 59.62 | 54.06 | 64.1 |
| 41.91 | 80.5 | 60.56 | 55.93 | 65.07 | 60.27 | 54.64 | 64.67 |
| 42.91 | 80.78 | 61.19 | 56.67 | 65.63 | 60.51 | 55.6 | 65.22 |
| 43.91 | 81.06 | 61.81 | 57.4 | 66.17 | 61.54 | 56.35 | 65.77 |
| 44.9 | 81.02 | 62.43 | 58.11 | 66.69 | 62.15 | 57.08 | 64.31 |
| 45.9 | 80.64 | 63.03 | 58.81 | 67.23 | 62.76 | 57.79 | 66.84 |
| 46.9 | 74.79 | 63.62 | 59.5 | 67.73 | 63.36 | 58.5 | 67.35 |
| 47.9 | 76.53 | 64.21 | 60.16 | 68.22 | 63.94 | 59.18 | 67.83 |
| 48.89 | 73.16 | 64.77 | 60.82 | 68.59 | 64.5 | 59.85 | 68.21 |
| 49.89 | 71.87 | 65.29 | 61.45 | 68.88 | 65.03 | 60.49 | 68.5 |
| 50.89 | 72.13 | 65.77 | 62.05 | 69.07 | 65.51 | 61.11 | 68.7 |
| 51.89 | 72.47 | 64.21 | 62.61 | 69.18 | 65.93 | 61.7 | 68.83 |
| 52.89 | 72.92 | 66.58 | 63.14 | 69.23 | 66.31 | 62.26 | 68.91 |
| 53.89 | 73.36 | 66.9 | 63.64 | 69.28 | 66.63 | 62.79 | 68.98 |
| 54.88 | 73.71 | 67.18 | 64.11 | 69.34 | 66.92 | 63.29 | 69.05 |
| 55.88 | 74.36 | 67.43 | 64.55 | 69.41 | 67.17 | 63.76 | 69.14 |
| 56.88 | 74.68 | 67.65 | 64.96 | 69.5 | 67.4 | 64.2 | 69.24 |
| 57.88 | 75.08 | 67.87 | 65.35 | 69.63 | 67.62 | 64.63 | 69.37 |
| 58.87 | 75.38 | 68.07 | 65.72 | 69.77 | 67.84 | 65.03 | 69.51 |
| 59.87 | 75.81 | 68.28 | 66.08 | 69.92 | 68.05 | 65.4 | 69.68 |
| 60.87 | 76.13 | 68.48 | 66.42 | 70.09 | 68.26 | 65.77 | 69.85 |
| 61.87 | 76.54 | 68.69 | 66.74 | 70.28 | 68.47 | 66.11 | 70.05 |
| 62.86 | 76.94 | 68.91 | 67.05 | 70.48 | 68.68 | 64.44 | 70.25 |
| 63.86 | 77.31 | 69.12 | 67.35 | 70.69 | 68.9 | 64.76 | 70.46 |
| 64.86 | 77.72 | 69.34 | 67.65 | 70.91 | 69.12 | 67.07 | 70.69 |
| 65.86 | 78.04 | 69.56 | 67.93 | 71.14 | 69.35 | 67.37 | 70.92 |
| 66.86 | 78.34 | 69.78 | 68.2 | 71.38 | 69.58 | 67.64 | 71.16 |
| 67.85 | 78.78 | 70.01 | 68.48 | 71.63 | 69.82 | 67.95 | 71.41 |
| 68.85 | 78.96 | 70.25 | 68.74 | 71.88 | 70.06 | 68.23 | 71.67 |
| 69.85 | 78.95 | 70.49 | 69.01 | 72.15 | 70.3 | 68.5 | 71.93 |
| 70.85 | 78.44 | 70.73 | 69.27 | 72.4 | 70.55 | 68.77 | 72.19 |
| 71.85 | 77.92 | 70.99 | 69.53 | 72.65 | 70.8 | 69.04 | 72.44 |
| 72.84 | 77.65 | 71.2 | 69.75 | 72.86 | 71.05 | 69.31 | 72.69 |

note using h = 120 W/ $m^2$ K, K = 0.19 W/m K, Alpha = 1.09 x $10^7$ $m^2$/sec
top radius = 5.08 cm small radius = 2.54 cm, height = 7.62 cm
number of node in small radius = 15 and number of node in height = 15
This is the interporated data to show temperature for every minutes

Table C-9 Experimental and simulated data for the cone # 3. Experiment 1

| Time | Temperature (°C) | | | | | | |
|---|---|---|---|---|---|---|---|
| (min) | Water | Exp 1 | Exp 2 | Exp 3 | Sim 1 | Sim 2 | Sim 3 |
| 0 | 21.78 | 21.69 | 21.53 | 21.52 | 21.58 | 21.58 | 21.58 |
| 1.99 | 86.05 | 22.21 | 21.67 | 21.67 | 21.58 | 21.58 | 21.58 |
| 2.99 | 86.56 | 22.21 | 21.7 | 21.6 | 21.72 | 21.58 | 21.58 |
| 3.98 | 86.7 | 22.03 | 21.81 | 21.6 | 22.31 | 21.58 | 21.6 |
| 4.98 | 86.67 | 22.47 | 21.85 | 21.79 | 23.42 | 21.58 | 21.67 |
| 5.98 | 86.85 | 25.62 | 22.01 | 21.96 | 24.83 | 21.6 | 21.86 |
| 6.97 | 86.85 | 27.4 | 22.06 | 22.22 | 26.66 | 21.65 | 22.22 |
| 7.97 | 86.85 | 27.74 | 22.33 | 22.82 | 28.51 | 21.78 | 22.78 |
| 8.96 | 86.85 | 28.26 | 22.65 | 23.61 | 30.39 | 22 | 23.52 |
| 9.96 | 86.85 | 30.58 | 23.18 | 24.54 | 32.24 | 22.35 | 24.43 |
| 10.95 | 86.85 | 33.82 | 23.62 | 25.55 | 34.06 | 22.83 | 25.46 |
| 11.95 | 86.85 | 35.85 | 24.08 | 26.4 | 35.82 | 23.45 | 26.66 |
| 12.95 | 86.85 | 37 | 24.83 | 27.62 | 37.51 | 24.2 | 27.94 |
| 13.94 | 86.85 | 38.83 | 26.08 | 28.18 | 39.14 | 25.07 | 28.28 |
| 14.94 | 86.85 | 40.45 | 27.21 | 30.66 | 40.7 | 26.04 | 31.68 |
| 15.93 | 86.85 | 41.77 | 27.85 | 31.67 | 42.2 | 27.1 | 32.11 |
| 16.93 | 86.85 | 43.24 | 29.2 | 33.2 | 43.63 | 28.24 | 33.57 |
| 17.93 | 86.85 | 44.79 | 30.44 | 34.58 | 45.01 | 29.43 | 35.03 |
| 18.92 | 86.85 | 46.01 | 31.66 | 35.98 | 46.34 | 30.67 | 36.49 |
| 19.92 | 86.85 | 47.47 | 33.02 | 37.4 | 47.61 | 31.84 | 37.85 |
| 20.91 | 86.85 | 48.78 | 34.25 | 38.72 | 48.84 | 33.23 | 39.36 |
| 21.91 | 86.85 | 49.18 | 34.73 | 39.97 | 50.02 | 34.54 | 40.81 |
| 22.91 | 86.85 | 50.92 | 36.76 | 41.38 | 51.16 | 35.85 | 42.21 |
| 23.9 | 86.85 | 52.55 | 38.45 | 43.08 | 52.26 | 37.17 | 43.58 |
| 24.9 | 86.85 | 53.42 | 39.56 | 44.19 | 53.33 | 38.48 | 44.82 |
| 25.89 | 86.85 | 54.71 | 41.01 | 45.63 | 54.36 | 39.78 | 46.23 |
| 26.89 | 86.85 | 55.53 | 42.21 | 46.78 | 55.36 | 41.06 | 47.5 |
| 27.89 | 86.85 | 56.59 | 43.48 | 48.09 | 56.32 | 42.33 | 48.75 |
| 28.88 | 86.92 | 57.39 | 44.61 | 49.13 | 57.26 | 43.59 | 49.96 |
| 29.88 | 87.23 | 58.69 | 46.15 | 50.49 | 58.17 | 44.82 | 51.14 |
| 30.87 | 87.11 | 59.41 | 47.16 | 51.5 | 59.05 | 46.03 | 52.28 |
| 31.87 | 87.03 | 60.32 | 48.3 | 52.54 | 59.8 | 47.21 | 53.36 |
| 32.86 | 86.68 | 61.14 | 49.38 | 53.53 | 60.74 | 48.37 | 54.47 |
| 33.86 | 86.87 | 61.8 | 50.44 | 54.48 | 61.54 | 49.51 | 55.52 |
| 34.86 | 87.05 | 62.88 | 51.67 | 55.73 | 62.33 | 50.62 | 56.53 |
| 35.85 | 86.81 | 63.5 | 52.58 | 56.6 | 63.09 | 51.7 | 57.52 |
| 36.85 | 87.04 | 64.26 | 53.65 | 57.56 | 63.83 | 52.76 | 58.47 |
| 37.84 | 87.03 | 65.06 | 54.58 | 58.43 | 64.55 | 53.78 | 59.4 |
| 38.84 | 87.1 | 65.84 | 55.68 | 59.44 | 65.24 | 54.8 | 60.28 |
| 39.84 | 87.17 | 66.69 | 56.78 | 60.48 | 65.92 | 55.78 | 61.16 |

Table C-9 —continued

| Time | Temperature (°C) | | | | | | |
|---|---|---|---|---|---|---|---|
| (min) | Water | Exp 1 | Exp 2 | Exp 3 | Sim 1 | Sim 2 | Sim 3 |
| 40.83 | 87 | 67.18 | 57.62 | 61.18 | 66.57 | 56.73 | 62 |
| 41.83 | 86.93 | 67.7 | 58.43 | 61.88 | 67.21 | 57.66 | 62.82 |
| 42.82 | 87.04 | 68.56 | 59.45 | 62.92 | 67.83 | 58.57 | 63.61 |
| 43.82 | 86.83 | 68.96 | 60.08 | 63.46 | 68.43 | 59.45 | 64.37 |
| 44.82 | 86.98 | 69.55 | 61.04 | 64.37 | 69.01 | 60.3 | 65.11 |
| 45.81 | 87.04 | 70.22 | 61.85 | 65.21 | 69.57 | 61.13 | 65.83 |
| 46.81 | 86.96 | 70.67 | 62.74 | 65.78 | 70.12 | 61.94 | 66.52 |
| 47.8 | 87.09 | 71.28 | 63.53 | 66.58 | 70.64 | 62.72 | 67.19 |
| 48.8 | 87 | 71.74 | 64.35 | 67.36 | 71.16 | 63.48 | 67.84 |
| 49.8 | 86.94 | 72.3 | 65.09 | 67.84 | 71.65 | 64.22 | 68.47 |
| 50.79 | 87.01 | 72.63 | 65.69 | 68.49 | 72.14 | 64.94 | 69.07 |
| 51.79 | 87.02 | 73.08 | 66.38 | 69.05 | 72.6 | 65.64 | 69.66 |
| 52.78 | 86.86 | 73.45 | 66.89 | 69.41 | 73.06 | 66.31 | 70.23 |
| 53.78 | 86.91 | 73.96 | 67.69 | 70.14 | 73.5 | 66.97 | 70.77 |
| 54.77 | 87.04 | 74.54 | 68.41 | 70.85 | 73.93 | 67.6 | 71.3 |
| 55.77 | 87.03 | 74.83 | 68.95 | 71.26 | 74.34 | 68.22 | 71.82 |
| 56.77 | 86.87 | 75.13 | 69.45 | 71.65 | 74.74 | 68.82 | 72.31 |
| 57.76 | 86.8 | 75.43 | 69.97 | 72.1 | 75.13 | 69.39 | 72.8 |
| 58.76 | 87.05 | 75.96 | 70.57 | 72.71 | 75.51 | 69.95 | 73.26 |

note using h = 135 W/m$^2$ K, K = 0.19 W/m K, Alpha = $1.09 \times 10^{-7}$ m$^2$/sec
top radius = 5.08 cm, small radius = 1.27 cm, height = 12.7 cm
number of node in small radius =8 and number of node in height = 20
This is the interporated data to show temperature for every minutes

Table C-10 Experimental and simulated data for the cone #3, Experiment 2

| Time (min) | Temperature (°C) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Water | Exp 1 | Exp 2 | Exp 3 | Sim 1 | Sim 2 | Sim 3 |
| 0 | 25.08 | 25.44 | 25.64 | 25.42 | 25.5 | 25.5 | 25.5 |
| 1.99 | 83.87 | 25.79 | 26.04 | 25.69 | 25.59 | 25.5 | 25.5 |
| 2.99 | 84.19 | 26.29 | 26.27 | 25.88 | 26.07 | 25.5 | 25.51 |
| 3.98 | 84.12 | 27.23 | 26.28 | 25.93 | 27.04 | 25.5 | 25.57 |
| 4.98 | 84.1 | 28.46 | 26.27 | 26.01 | 28.38 | 25.52 | 25.72 |
| 5.97 | 84.09 | 29.87 | 26.33 | 26.29 | 29.93 | 25.56 | 26.04 |
| 6.97 | 84.11 | 31.45 | 26.49 | 26.71 | 31.59 | 25.66 | 26.52 |
| 7.97 | 84.02 | 33.05 | 26.65 | 27.2 | 33.29 | 25.85 | 27.17 |
| 8.96 | 84.03 | 34.56 | 26.98 | 27.94 | 34.97 | 26.16 | 27.98 |
| 9.96 | 84.1 | 36.42 | 27.58 | 28.98 | 36.61 | 26.58 | 28.93 |
| 10.95 | 83.85 | 37.51 | 27.82 | 29.58 | 38.19 | 27.13 | 29.98 |
| 11.95 | 84.11 | 39.43 | 28.82 | 31.05 | 39.72 | 27.8 | 31.12 |
| 12.94 | 84.09 | 40.73 | 29.46 | 32.07 | 41.19 | 28.57 | 32.33 |
| 13.94 | 84.02 | 42.07 | 30.37 | 33.16 | 42.6 | 29.44 | 33.58 |
| 14.94 | 84.04 | 43.49 | 31.37 | 34.38 | 43.95 | 30.39 | 34.87 |
| 15.93 | 84.09 | 44.86 | 32.33 | 35.6 | 45.24 | 31.4 | 36.18 |
| 16.93 | 84.02 | 46.07 | 33.32 | 36.79 | 46.48 | 32.47 | 37.5 |
| 17.92 | 83.93 | 47.14 | 34.31 | 37.98 | 47.68 | 33.58 | 38.81 |
| 18.92 | 84.15 | 48.55 | 35.73 | 39.46 | 48.82 | 34.72 | 40.12 |
| 19.91 | 83.86 | 49.36 | 36.49 | 40.48 | 49.93 | 35.88 | 41.42 |
| 20.91 | 84.23 | 50.82 | 38 | 42 | 51 | 37.06 | 42.7 |
| 21.91 | 83.88 | 51.53 | 38.82 | 42.85 | 52.03 | 38.24 | 43.96 |
| 22.9 | 84.18 | 52.81 | 40.36 | 44.28 | 53.02 | 39.42 | 45.19 |
| 23.9 | 84.08 | 53.7 | 41.4 | 45.43 | 53.98 | 40.6 | 46.4 |
| 24.89 | 83.88 | 54.45 | 42.4 | 46.33 | 54.91 | 41.77 | 47.58 |
| 25.89 | 84.14 | 55.6 | 43.75 | 47.72 | 55.81 | 42.93 | 48.73 |
| 26.88 | 84.19 | 56.59 | 45.03 | 48.87 | 56.68 | 44.08 | 49.85 |
| 27.88 | 84.17 | 57.38 | 46.02 | 49.81 | 57.52 | 45.2 | 50.94 |
| 28.88 | 84.09 | 58.12 | 47.02 | 50.8 | 58.34 | 46.31 | 52 |
| 29.87 | 84.22 | 59.11 | 48.25 | 51.93 | 59.13 | 47.4 | 53.03 |
| 30.87 | 84.06 | 59.79 | 49.11 | 52.75 | 59.9 | 48.47 | 54.03 |
| 31.86 | 84.06 | 60.51 | 50.14 | 53.66 | 60.65 | 49.51 | 55 |
| 32.86 | 84.21 | 61.43 | 51.3 | 54.85 | 61.37 | 50.54 | 55.94 |
| 33.85 | 83.95 | 61.91 | 52.01 | 55.48 | 62.07 | 51.53 | 56.86 |
| 34.85 | 84.18 | 62.84 | 53.13 | 56.58 | 62.75 | 52.51 | 57.74 |
| 35.85 | 84.13 | 63.43 | 54.03 | 57.4 | 63.42 | 53.46 | 58.6 |
| 36.84 | 83.46 | 64.1 | 54.8 | 58.06 | 64.06 | 54.39 | 59.43 |
| 37.84 | 82.55 | 64.81 | 55.89 | 59.05 | 64.68 | 55.3 | 60.24 |
| 38.83 | 75.87 | 65.37 | 56.69 | 59.84 | 65.28 | 56.18 | 61.02 |
| 39.83 | 74.94 | 65.83 | 57.41 | 60.37 | 65.85 | 57.03 | 61.77 |

Table C.10 --continued.

| Time (min) | Temperature (°C) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Water | Exp 1 | Exp 2 | Exp 3 | Sim 1 | Sim 2 | Sim 3 |
| 40.82 | 74.57 | 66.59 | 58.39 | 61.43 | 66.36 | 57.87 | 62.5 |
| 41.82 | 74.65 | 67.05 | 59.12 | 62.07 | 66.78 | 58.68 | 63.2 |
| 42.81 | 75.33 | 67.15 | 59.66 | 62.54 | 67.12 | 59.47 | 63.86 |
| 43.81 | 76.44 | 67.75 | 60.7 | 63.36 | 67.4 | 60.23 | 64.48 |
| 44.81 | 77.3 | 68.09 | 61.34 | 64.02 | 67.65 | 60.96 | 65.05 |
| 45.8 | 78.1 | 68.39 | 62.07 | 64.66 | 67.89 | 61.66 | 65.58 |
| 46.8 | 78.88 | 68.71 | 62.79 | 65.23 | 68.13 | 62.32 | 66.06 |
| 47.79 | 79.56 | 68.89 | 63.26 | 65.58 | 68.39 | 62.94 | 66.5 |
| 48.79 | 80.17 | 69.06 | 63.82 | 66.03 | 68.66 | 63.52 | 66.91 |
| 49.78 | 80.9 | 69.39 | 64.48 | 66.55 | 68.95 | 64.07 | 67.3 |
| 50.78 | 81.43 | 69.68 | 64.89 | 66.85 | 69.26 | 64.58 | 67.67 |
| 51.78 | 82.12 | 70.03 | 65.59 | 67.35 | 69.58 | 65.06 | 68.02 |
| 52.77 | 82.63 | 70.19 | 65.9 | 67.55 | 69.92 | 65.52 | 68.37 |
| 53.77 | 83.28 | 70.57 | 66.32 | 68.01 | 70.27 | 65.96 | 68.71 |
| 54.76 | 83.88 | 70.99 | 66.35 | 68.55 | 70.64 | 64.39 | 69.05 |
| 55.76 | 84.14 | 71.34 | 67.4 | 68.93 | 71.01 | 66.8 | 69.38 |
| 56.75 | 84.16 | 71.69 | 67.84 | 69.31 | 71.4 | 67.2 | 69.72 |
| 57.75 | 84.12 | 71.97 | 68.13 | 69.56 | 71.79 | 67.59 | 70.07 |
| 58.75 | 86.05 | 72.33 | 68.41 | 69.85 | 72.18 | 67.98 | 70.41 |

note using h = 140 W/m$^2$ K, K = 0.15 W/m K, Alpha = 1.09 x 10$^{-7}$ m$^2$/sec
top radius = 5.08 cm small radius = 1.27 cm height = 12.7 cm
number of node in small radius =8 and number of node in height = 20
This is the interporated data to show temperature for every minutes

# APPENDIX D

## SIMULATED HEATING, COOLING AND TOTAL PROCESSING TIME

Table D-1 Simulated heating cooling and total processing time for conduction heating foods in the conical shaped containers

Target Fo = 3 min (based on Z = 10 C Initial temperature = 20 C and Final Temperature after cooling= 50° C)

A. Cone #1 with infinite heat transfer coefficient

| Temperature (C) | Alpha = 1.2 m2/sec | | | Alpha = 1.4 m2/sec | | | Alpha = 1.6 m2/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | Heating (min) | Cooling (min) | Total (min) | Heating (min) | Cooling (min) | Total (min) | Heating (min) | Cooling (min) | Total (min) |
| 110 | 131.63 | 47.87 | 179.50 | 118.91 | 40.97 | 159.88 | 109.84 | 36.95 | 146.79 |
| 112 | 115.86 | 48.86 | 164.72 | 103.42 | 41.97 | 145.39 | 93.86 | 36.95 | 130.81 |
| 114 | 102.72 | 48.86 | 151.58 | 91.43 | 41.97 | 133.40 | 82.88 | 36.95 | 119.83 |
| 116 | 93.24 | 49.86 | 143.10 | 82.44 | 41.97 | 124.41 | 74.39 | 37.94 | 112.33 |
| 118 | 85.89 | 49.86 | 135.75 | 75.44 | 42.97 | 118.41 | 67.90 | 37.94 | 105.84 |
| 120 | 79.78 | 49.86 | 129.64 | 69.95 | 42.97 | 112.92 | 63.12 | 37.94 | 101.06 |
| 122 | 75.04 | 50.86 | 125.90 | 65.45 | 42.97 | 108.42 | 58.42 | 37.94 | 96.36 |
| 124 | 70.13 | 50.86 | 120.99 | 61.65 | 43.97 | 105.62 | 54.92 | 38.94 | 93.86 |
| 126 | 66.32 | 50.86 | 117.18 | 57.95 | 43.97 | 101.92 | 52.18 | 38.94 | 91.12 |
| 128 | 63.08 | 50.86 | 113.94 | 55.09 | 43.97 | 99.06 | 49.18 | 38.94 | 88.12 |
| 130 | 60.34 | 51.86 | 112.20 | 52.46 | 43.97 | 96.43 | 47.18 | 38.94 | 86.12 |
| 132 | 58.46 | 51.86 | 110.32 | 50.22 | 43.97 | 94.19 | 45.19 | 38.94 | 84.13 |
| 134 | 55.33 | 51.86 | 107.19 | 48.22 | 44.97 | 93.19 | 43.56 | 38.94 | 82.50 |
| 136 | 53.48 | 51.86 | 105.34 | 46.59 | 44.97 | 91.56 | 41.07 | 39.94 | 81.01 |
| 138 | 51.36 | 51.86 | 103.22 | 45.09 | 44.97 | 90.06 | 40.07 | 39.94 | 80.01 |
| 140 | 50.11 | 51.86 | 101.97 | 43.10 | 44.97 | 88.07 | 38.20 | 39.94 | 78.14 |

Table D-1—continued

B Cone #1 with heat transfer coefficient 300 m2/s

| Temperature (C) | Alpha = 1.2 m2/sec | | | Alpha = 1.4 m2/sec | | | Alpha = 1.6 m2/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | Heating (min) | Cooling (min) | Total (min) | Heating (min) | Cooling (min) | Total (min) | Heating (min) | Cooling (min) | Total (min) |
| 110 | 138.56 | 47.48 | 186.04 | 125.86 | 40.96 | 166.82 | 116.94 | 35.98 | 152.92 |
| 112 | 121.94 | 48.47 | 170.41 | 109.88 | 41.95 | 151.83 | 100.95 | 36.98 | 137.93 |
| 114 | 109.08 | 48.47 | 157.55 | 97.37 | 41.95 | 139.32 | 88.96 | 36.98 | 125.94 |
| 116 | 99.19 | 49.46 | 148.65 | 88.40 | 41.95 | 130.35 | 80.47 | 37.98 | 118.45 |
| 118 | 91.01 | 49.46 | 140.47 | 80.91 | 42.95 | 123.86 | 73.47 | 37.98 | 111.45 |
| 120 | 85.32 | 49.46 | 134.78 | 75.17 | 42.95 | 118.12 | 67.97 | 37.98 | 105.95 |
| 122 | 79.64 | 49.46 | 129.10 | 70.42 | 42.95 | 113.37 | 63.47 | 37.98 | 101.45 |
| 124 | 75.43 | 50.45 | 125.88 | 66.18 | 42.95 | 109.13 | 60.22 | 37.98 | 98.20 |
| 126 | 71.48 | 50.45 | 121.93 | 63.19 | 43.95 | 107.14 | 56.48 | 38.98 | 95.46 |
| 128 | 67.53 | 50.45 | 117.98 | 60.19 | 43.95 | 104.14 | 54.10 | 38.98 | 93.08 |
| 130 | 64.56 | 50.45 | 115.01 | 56.94 | 43.95 | 100.89 | 51.11 | 38.98 | 90.09 |
| 132 | 61.83 | 51.44 | 113.27 | 54.44 | 43.95 | 98.39 | 49.59 | 38.98 | 88.57 |
| 134 | 59.51 | 51.44 | 110.95 | 52.20 | 43.95 | 96.15 | 47.60 | 38.98 | 86.58 |
| 136 | 58.00 | 51.44 | 109.44 | 50.57 | 44.95 | 95.52 | 45.11 | 38.98 | 84.09 |
| 138 | 56.02 | 51.44 | 107.46 | 48.45 | 44.95 | 93.40 | 43.48 | 39.98 | 83.46 |
| 140 | 53.42 | 51.44 | 104.86 | 47.57 | 44.95 | 92.52 | 41.98 | 39.98 | 81.96 |

Table D-1—continued

C. Case # 2 with infinite surface heat transfer coefficient

| Temperature ( C) | Alpha = 1.2 m2/sec. | | | Alpha = 1.4 m2/sec. | | | Alpha = 1.6 m2/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | Heating (min) | Cooling (min) | Total (min) | Heating (min) | Cooling (min) | Total (min) | Heating (min) | Cooling (min) | Total (min) |
| 110 | 93.51 | 24.82 | 118.33 | 86.48 | 21.99 | 108.47 | 79.86 | 19.96 | 99.82 |
| 112 | 78.69 | 24.82 | 103.51 | 71.01 | 21.99 | 93.00 | 66.01 | 19.93 | 85.94 |
| 114 | 68.02 | 25.81 | 93.83 | 61.15 | 21.99 | 83.14 | 56.53 | 19.93 | 76.46 |
| 116 | 61.23 | 25.81 | 87.04 | 54.04 | 22.99 | 77.03 | 48.98 | 19.93 | 68.91 |
| 118 | 54.96 | 25.81 | 80.77 | 49.48 | 22.99 | 72.47 | 43.92 | 20.96 | 64.88 |
| 120 | 50.98 | 26.80 | 77.78 | 45.21 | 22.99 | 68.20 | 40.06 | 20.93 | 60.99 |
| 122 | 47.81 | 26.80 | 74.61 | 41.50 | 22.99 | 64.49 | 36.94 | 20.96 | 57.90 |
| 124 | 44.76 | 26.80 | 71.56 | 39.00 | 22.99 | 61.99 | 34.44 | 20.93 | 55.37 |
| 126 | 41.59 | 26.80 | 68.39 | 36.19 | 23.99 | 60.18 | 32.60 | 20.93 | 53.53 |
| 128 | 39.16 | 26.80 | 65.96 | 34.20 | 23.99 | 58.19 | 30.98 | 20.93 | 51.91 |
| 130 | 37.29 | 26.80 | 64.09 | 32.45 | 23.99 | 56.44 | 29.85 | 20.93 | 50.78 |
| 132 | 35.89 | 27.80 | 63.69 | 31.92 | 23.99 | 55.91 | 27.99 | 21.92 | 49.91 |
| 134 | 34.84 | 27.80 | 62.64 | 30.08 | 23.99 | 54.07 | 26.52 | 21.92 | 48.46 |
| 136 | 33.05 | 27.80 | 60.85 | 28.58 | 23.99 | 52.57 | 25.27 | 21.92 | 47.19 |
| 138 | 31.53 | 27.80 | 59.33 | 27.21 | 23.99 | 51.20 | 24.27 | 21.92 | 46.19 |
| 140 | 30.24 | 27.80 | 58.04 | 26.21 | 23.99 | 50.20 | 23.49 | 21.92 | 45.41 |

Table D-1--continued

D Cone # 2 with heat transfer coefficient 300 m2/s

| Temperature ( C) | Alpha = 1.2 m2/sec | | | Alpha = 1.4 m2/sec | | | Alpha = 1.6 m2/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | Heating | Cooling | Total | Heating | Cooling | Total | Heating | Cooling | Total |
| | (min) | (min) | (min) | (min) | (min) | (min) | (min) | (min) | (min) |
| 110 | 101.50 | 24.82 | 126.32 | 93.46 | 21.99 | 115.45 | 87.82 | 19.93 | 107.75 |
| 112 | 85.87 | 25.81 | 111.68 | 79.09 | 21.99 | 101.08 | 73.37 | 19.93 | 93.30 |
| 114 | 75.69 | 25.81 | 101.50 | 68.53 | 21.99 | 90.52 | 63.34 | 19.93 | 83.27 |
| 116 | 68.12 | 25.81 | 93.93 | 61.60 | 22.99 | 84.59 | 55.93 | 19.93 | 75.86 |
| 118 | 62.17 | 25.81 | 87.98 | 55.23 | 22.99 | 78.22 | 51.07 | 20.93 | 72.00 |
| 120 | 56.58 | 26.80 | 83.38 | 51.54 | 22.99 | 74.53 | 46.34 | 20.93 | 67.27 |
| 122 | 52.76 | 26.80 | 79.56 | 47.29 | 22.99 | 70.28 | 42.98 | 20.93 | 63.91 |
| 124 | 50.26 | 26.80 | 77.06 | 44.29 | 22.99 | 67.28 | 40.42 | 20.93 | 61.35 |
| 126 | 46.66 | 26.80 | 73.46 | 42.26 | 23.99 | 66.25 | 38.77 | 20.93 | 59.70 |
| 128 | 44.81 | 26.80 | 71.61 | 39.89 | 23.99 | 63.88 | 36.69 | 20.93 | 57.62 |
| 130 | 42.58 | 26.80 | 69.38 | 38.01 | 23.99 | 62.00 | 34.01 | 20.93 | 54.94 |
| 132 | 40.78 | 27.80 | 68.58 | 36.64 | 23.99 | 60.63 | 32.95 | 21.92 | 54.87 |
| 134 | 39.48 | 27.80 | 67.28 | 34.55 | 23.99 | 58.54 | 31.17 | 21.92 | 53.09 |
| 136 | 37.36 | 27.80 | 65.16 | 33.89 | 23.99 | 57.88 | 30.71 | 21.92 | 52.63 |
| 138 | 35.74 | 27.80 | 63.54 | 32.39 | 23.99 | 56.38 | 29.48 | 21.92 | 51.40 |
| 140 | 35.05 | 27.80 | 62.85 | 31.13 | 23.99 | 55.12 | 28.15 | 21.92 | 50.07 |

Table D-1--continued

E. Cone # 3 with infinite surface heat transfer coefficient

| Temperature (C) | Alpha = 1.2 m2/sec | | | Alpha = 1.4 m2/sec | | | Alpha = 1.6 m2/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | Heating | Cooling | Total | Heating | Cooling | Total | Heating | Cooling | Total |
| | (min) | (min) | (min) | (min) | (min) | (min) | (min) | (min) | (min) |
| 110 | 120.53 | 40.84 | 161.37 | 108.75 | 35.92 | 144.67 | 100.72 | 30.91 | 131.63 |
| 112 | 104.10 | 40.57 | 144.67 | 93.29 | 35.61 | 128.90 | 85.26 | 31.75 | 117.01 |
| 114 | 92.15 | 41.56 | 133.71 | 82.06 | 35.61 | 117.67 | 75.04 | 31.75 | 106.79 |
| 116 | 83.92 | 41.56 | 125.48 | 73.83 | 36.91 | 110.74 | 67.06 | 31.75 | 98.81 |
| 118 | 76.95 | 41.56 | 118.51 | 67.34 | 36.60 | 103.94 | 61.08 | 32.74 | 93.82 |
| 120 | 70.73 | 42.83 | 113.56 | 62.11 | 36.60 | 98.71 | 55.84 | 32.91 | 88.75 |
| 122 | 66.37 | 42.55 | 108.92 | 57.87 | 36.91 | 94.78 | 51.85 | 32.91 | 84.76 |
| 124 | 62.39 | 42.55 | 104.94 | 54.37 | 37.59 | 91.96 | 49.11 | 32.74 | 81.85 |
| 126 | 58.84 | 42.55 | 101.39 | 51.51 | 37.59 | 89.10 | 46.49 | 32.74 | 79.23 |
| 128 | 55.78 | 43.83 | 99.61 | 49.14 | 37.59 | 86.73 | 43.38 | 33.74 | 77.12 |
| 130 | 53.42 | 43.54 | 96.96 | 46.52 | 37.59 | 84.11 | 41.51 | 33.74 | 75.25 |
| 132 | 50.94 | 43.54 | 94.48 | 44.52 | 37.59 | 82.11 | 39.39 | 33.74 | 73.13 |
| 134 | 48.81 | 43.83 | 92.64 | 42.40 | 37.59 | 79.99 | 38.46 | 33.74 | 72.20 |
| 136 | 46.95 | 43.54 | 90.49 | 41.47 | 38.58 | 80.05 | 36.15 | 33.74 | 69.89 |
| 138 | 45.45 | 44.53 | 89.98 | 39.47 | 38.58 | 78.05 | 35.52 | 33.74 | 69.26 |
| 140 | 44.39 | 44.53 | 88.92 | 38.54 | 38.58 | 77.12 | 34.03 | 33.74 | 67.77 |

Table D-1—continued

F  Cone # 3 with heat transfer coefficient 300 m2/s

|  | Alpha = 1.2 m2/sec |  |  | Alpha = 1.4 m2/sec |  |  | Alpha = 1.6 m2/sec |  |  |
|---|---|---|---|---|---|---|---|---|---|
| Temperature | Heating | Cooling | Total | Heating | Cooling | Total | Heating | Cooling | Total |
| (C) | (min) | (min) | (min) | (min) | (min) | (min) | (min) | (min) | (min) |
| 110 | 125.68 | 40.57 | 166.25 | 114.75 | 35.61 | 150.36 | 107.16 | 30.76 | 137.92 |
| 112 | 109.36 | 40.57 | 149.93 | 98.92 | 35.61 | 134.53 | 91.28 | 31.75 | 123.03 |
| 114 | 97.48 | 41.56 | 139.04 | 87.56 | 35.61 | 123.17 | 80.37 | 31.75 | 112.12 |
| 116 | 88.07 | 41.56 | 129.63 | 79.14 | 36.60 | 115.74 | 71.94 | 31.75 | 103.69 |
| 118 | 81.15 | 41.56 | 122.71 | 72.21 | 36.60 | 108.81 | 65.75 | 32.74 | 98.49 |
| 120 | 75.21 | 42.55 | 117.76 | 67.51 | 36.60 | 104.11 | 60.52 | 32.74 | 93.26 |
| 122 | 70.40 | 42.55 | 112.95 | 62.59 | 36.60 | 99.19 | 56.56 | 32.74 | 89.30 |
| 124 | 66.30 | 42.55 | 108.85 | 58.99 | 36.60 | 95.59 | 53.09 | 32.74 | 85.83 |
| 126 | 62.97 | 42.55 | 105.52 | 55.55 | 37.59 | 93.14 | 50.11 | 32.74 | 82.85 |
| 128 | 59.63 | 43.54 | 103.17 | 52.70 | 37.59 | 90.29 | 48.24 | 32.74 | 80.98 |
| 130 | 56.91 | 43.54 | 100.45 | 51.05 | 37.59 | 88.64 | 45.78 | 33.74 | 79.52 |
| 132 | 54.56 | 43.54 | 98.10 | 48.60 | 37.59 | 86.19 | 43.79 | 33.74 | 77.53 |
| 134 | 53.06 | 43.54 | 96.60 | 46.62 | 37.59 | 84.21 | 41.92 | 33.74 | 75.66 |
| 136 | 51.08 | 43.54 | 94.62 | 45.11 | 37.59 | 82.70 | 39.84 | 33.74 | 73.58 |
| 138 | 48.57 | 43.54 | 92.11 | 42.81 | 38.58 | 81.39 | 39.02 | 33.74 | 72.76 |
| 140 | 47.13 | 44.53 | 91.66 | 41.79 | 38.58 | 80.37 | 37.29 | 33.74 | 71.03 |

Table D-2 Simulated heating cooling and total processing time for conduction heating foods in the elliptical containers
Target Fo = 3 min (based on Z = 10 C Initial temperature = 20 C and Final Temperature after cooling = 50 C)

A. Ellipse #1 with infinite heat transfer coefficient

| Temperature ( C) | Alpha = 1.2 m2/sec | | | Alpha = 1.4 m2/sec | | | Alpha = 1.6 m2/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | Heating (min) | Cooling (min) | Total (min) | Heating (min) | Cooling (min) | Total (min) | Heating (min) | Cooling (min) | Total (min) |
| 110 | 107.10 | 22.86 | 129.96 | 97.63 | 19.82 | 117.45 | 90.50 | 17.80 | 108.30 |
| 112 | 91.45 | 23.86 | 115.30 | 82.51 | 19.82 | 102.33 | 75.66 | 17.80 | 93.46 |
| 114 | 80.45 | 23.86 | 104.30 | 71.86 | 20.81 | 92.67 | 65.40 | 17.80 | 83.20 |
| 116 | 72.31 | 23.86 | 96.17 | 64.18 | 20.81 | 84.99 | 58.04 | 18.79 | 76.83 |
| 118 | 65.91 | 24.85 | 90.76 | 58.29 | 20.81 | 79.11 | 52.48 | 18.79 | 71.27 |
| 120 | 60.88 | 24.85 | 85.73 | 53.65 | 20.81 | 74.46 | 48.12 | 18.79 | 66.91 |
| 122 | 56.72 | 24.85 | 81.57 | 49.80 | 21.81 | 71.61 | 44.57 | 18.79 | 63.36 |
| 124 | 53.18 | 24.85 | 78.03 | 46.65 | 21.81 | 68.45 | 41.66 | 18.79 | 60.45 |
| 126 | 50.20 | 24.85 | 75.04 | 43.92 | 21.81 | 65.72 | 39.16 | 19.78 | 58.94 |
| 128 | 47.59 | 25.84 | 73.43 | 41.60 | 21.81 | 63.40 | 37.03 | 19.78 | 56.81 |
| 130 | 45.29 | 25.84 | 71.13 | 39.54 | 21.81 | 61.34 | 35.17 | 19.78 | 54.95 |
| 132 | 43.27 | 25.84 | 69.11 | 37.73 | 22.80 | 60.52 | 33.52 | 19.78 | 53.30 |
| 134 | 41.44 | 25.84 | 67.28 | 36.10 | 22.80 | 58.90 | 32.05 | 19.78 | 51.83 |
| 136 | 39.79 | 25.84 | 65.63 | 34.63 | 22.80 | 57.42 | 30.74 | 19.78 | 50.52 |
| 138 | 38.30 | 25.84 | 64.14 | 33.31 | 22.80 | 56.11 | 29.55 | 19.78 | 49.33 |
| 140 | 36.93 | 26.84 | 63.77 | 32.10 | 22.80 | 54.90 | 28.45 | 19.78 | 48.23 |

Table D-2--continued

B Ellipse #1 with heat transfer coefficient 300 m2/s

| Temperature (C) | Alpha = 1.2 m2/sec | | | Alpha = 1.4 m2/sec | | | Alpha = 1.6 m2/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | Heating (min) | Cooling (min) | Total (min) | Heating (min) | Cooling (min) | Total (min) | Heating (min) | Cooling (min) | Total (min) |
| 110 | 116.17 | 22.86 | 139.03 | 106.80 | 19.82 | 126.62 | 99.89 | 17.80 | 117.69 |
| 112 | 100.14 | 23.86 | 124.00 | 91.31 | 19.82 | 111.13 | 84.56 | 17.80 | 102.36 |
| 114 | 88.71 | 23.86 | 112.57 | 80.34 | 20.81 | 101.16 | 73.93 | 17.80 | 91.73 |
| 116 | 80.14 | 23.86 | 103.99 | 72.23 | 20.81 | 93.04 | 66.20 | 17.80 | 84.01 |
| 118 | 73.43 | 24.85 | 98.28 | 65.91 | 20.81 | 86.72 | 60.21 | 18.79 | 79.00 |
| 120 | 67.99 | 24.85 | 92.84 | 60.89 | 20.81 | 81.71 | 55.45 | 18.79 | 74.24 |
| 122 | 63.49 | 24.85 | 88.34 | 56.74 | 21.81 | 78.55 | 51.61 | 18.79 | 70.41 |
| 124 | 59.73 | 24.85 | 84.58 | 53.27 | 21.81 | 75.08 | 48.37 | 18.79 | 67.16 |
| 126 | 56.47 | 24.85 | 81.32 | 50.30 | 21.81 | 72.11 | 45.62 | 18.79 | 64.41 |
| 128 | 53.64 | 25.64 | 79.49 | 47.73 | 21.81 | 69.53 | 43.73 | 18.79 | 62.52 |
| 130 | 51.13 | 25.84 | 76.97 | 45.44 | 21.81 | 67.24 | 41.14 | 19.78 | 60.92 |
| 132 | 48.92 | 25.84 | 74.77 | 43.44 | 21.81 | 65.24 | 39.30 | 19.78 | 59.08 |
| 134 | 46.92 | 25.64 | 72.76 | 41.63 | 22.80 | 64.42 | 37.64 | 19.78 | 57.43 |
| 136 | 45.10 | 25.64 | 70.94 | 40.02 | 22.80 | 62.81 | 36.16 | 19.78 | 55.94 |
| 138 | 43.00 | 25.84 | 68.64 | 38.53 | 22.80 | 61.33 | 34.80 | 19.78 | 54.58 |
| 140 | 41.96 | 25.64 | 67.81 | 37.18 | 22.80 | 59.98 | 33.58 | 19.78 | 53.36 |

Table D 2—continued

C Ellipse #2 with infinite heat transfer coefficient

| Temperature (C) | Alpha – 1 2 m2/sec | | | Alpha – 1 4 m2/sec | | | Alpha – 1 6 m2/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | Heating (min) | Cooling (min) | Total (min) | Heating (min) | Cooling (min) | Total (min) | Heating (min) | Cooling (min) | Total (min) |
| 110 | 83 17 | 14 72 | 97 89 | 77.04 | 11 93 | 88 97 | 72 26 | 10 74 | 83 00 |
| 112 | 68 57 | 14 72 | 83 29 | 62 50 | 12 92 | 75 42 | 57 98 | 10 74 | 68 72 |
| 114 | 58 76 | 14 72 | 73 48 | 52 93 | 12 92 | 65 86 | 48 58 | 11 72 | 60 30 |
| 116 | 51 76 | 14 72 | 66 48 | 46 22 | 12 92 | 59 15 | 42 05 | 11 72 | 53 77 |
| 118 | 46 49 | 15 70 | 62 19 | 41 32 | 12 92 | 54 24 | 37 38 | 11 72 | 49 10 |
| 120 | 42 44 | 15 70 | 58 14 | 37 56 | 12 92 | 50 48 | 33 81 | 11 72 | 45.53 |
| 122 | 39 19 | 15 70 | 54 89 | 34 54 | 13 92 | 48 46 | 31 03 | 11 72 | 42 75 |
| 124 | 36 52 | 15 70 | 52 22 | 32 09 | 13 92 | 46 01 | 28 74 | 11 72 | 40 46 |
| 126 | 34 25 | 15 70 | 49 96 | 30 05 | 13 92 | 43 97 | 26 85 | 12 69 | 39.55 |
| 128 | 32 32 | 15 70 | 48 02 | 28 30 | 13 92 | 42 22 | 25 27 | 12 69 | 37 96 |
| 130 | 30 64 | 15 70 | 46 34 | 26 79 | 13 92 | 40 71 | 23 88 | 12 69 | 36 57 |
| 132 | 29 16 | 16 68 | 45 85 | 25.47 | 13 92 | 39 39 | 22 67 | 12 69 | 35 37 |
| 134 | 27 85 | 16 68 | 44 53 | 24 31 | 13 92 | 38 22 | 21 62 | 12,69 | 34 31 |
| 136 | 26 68 | 16 68 | 43 36 | 23 25 | 13 92 | 37 17 | 20 67 | 12 69 | 33 36 |
| 138 | 25 61 | 16 68 | 42 29 | 22 30 | 13 92 | 36 22 | 19 81 | 12 69 | 32 50 |
| 140 | 24 64 | 16 68 | 41 32 | 21 45 | 14 91 | 36 36 | 19 04 | 12 69 | 31 73 |

Table D-2—continued

D Ellipse # 2 with heat transfer coefficient 300 m$^2$/s

| Temperature (C) | Alpha – 1.2 m2/sec. | | | Alpha – 1.4 m2/sec | | | Alpha – 1.6 m2/sec | | |
|---|---|---|---|---|---|---|---|---|---|
| | Heating (min) | Cooling (min) | Total (min) | Heating (min) | Cooling (min) | Total (min) | Heating (min) | Cooling (min) | Total (min) |
| 110 | 91.02 | 14.72 | 105.74 | 84.87 | 11.93 | 96.80 | 80.31 | 10.74 | 91.05 |
| 112 | 76.18 | 14.72 | 90.90 | 70.21 | 12.92 | 83.13 | 65.67 | 10.74 | 76.41 |
| 114 | 65.93 | 14.72 | 80.65 | 60.26 | 12.92 | 73.19 | 56.02 | 11.72 | 67.74 |
| 116 | 58.57 | 14.72 | 73.29 | 53.18 | 12.92 | 66.11 | 49.13 | 11.72 | 60.84 |
| 118 | 52.99 | 15.70 | 68.69 | 47.90 | 12.92 | 60.82 | 44.06 | 11.72 | 55.78 |
| 120 | 48.61 | 15.70 | 64.31 | 43.80 | 12.92 | 56.72 | 40.16 | 11.72 | 51.87 |
| 122 | 45.05 | 15.70 | 60.75 | 40.51 | 13.92 | 54.42 | 37.07 | 11.72 | 48.79 |
| 124 | 42.10 | 15.70 | 57.81 | 37.81 | 13.92 | 51.72 | 34.51 | 11.72 | 46.23 |
| 126 | 39.62 | 15.70 | 55.32 | 35.51 | 13.92 | 49.42 | 32.38 | 11.72 | 44.09 |
| 128 | 37.47 | 15.70 | 53.18 | 33.55 | 13.92 | 47.47 | 30.56 | 12.69 | 43.25 |
| 130 | 35.62 | 15.70 | 51.32 | 31.84 | 13.92 | 45.76 | 28.97 | 12.69 | 41.67 |
| 132 | 33.96 | 15.70 | 49.66 | 30.33 | 13.92 | 44.25 | 27.58 | 12.69 | 40.28 |
| 134 | 32.49 | 16.68 | 49.17 | 29.00 | 13.92 | 42.92 | 26.35 | 12.69 | 39.04 |
| 136 | 31.17 | 16.68 | 47.85 | 27.80 | 13.92 | 41.72 | 25.25 | 12.69 | 37.94 |
| 138 | 29.98 | 16.68 | 46.66 | 26.72 | 13.92 | 40.63 | 24.26 | 12.69 | 36.95 |
| 140 | 28.89 | 16.68 | 45.57 | 25.74 | 13.92 | 39.65 | 23.36 | 12.69 | 36.05 |

# APPENDIX E

# SIMULATED QUALITY RETENTION

Table E- 1 Simulated quality retention of foods with thermal diffusivity $1.2 \times 10^{-7}$ $m^2/s$ after thermal processing in the conically shaped container #1 $h = 300$ $w/m^2K$

**% Retention**

| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| 40.00 | 110.00 | 75.10 | 28.23 | 11.50 | 5.53 | 3.03 | 1.82 |
| | 112.00 | 71.76 | 29.29 | 13.53 | 7.24 | 4.32 | 2.79 |
| | 114.00 | 66.95 | 28.89 | 14.56 | 8.40 | 5.32 | 3.61 |
| | 116.00 | 61.90 | 28.57 | 15.59 | 9.59 | 6.38 | 4.49 |
| | 118.00 | 55.43 | 27.70 | 15.74 | 10.15 | 7.01 | 5.09 |
| | 120.00 | 49.90 | 25.76 | 15.82 | 10.64 | 7.60 | 5.66 |
| | 122.00 | 42.78 | 25.10 | 15.70 | 10.96 | 8.05 | 6.13 |
| | 124.00 | 38.26 | 23.59 | 16.04 | 11.59 | 8.73 | 6.78 |
| | 126.00 | 34.86 | 22.57 | 16.01 | 11.92 | 9.18 | 7.26 |
| | 128.00 | 29.84 | 21.00 | 15.46 | 11.81 | 9.28 | 7.45 |
| | 130.00 | 26.91 | 19.97 | 15.20 | 11.89 | 9.51 | 7.75 |
| | 132.00 | 24.30 | 19.00 | 14.88 | 11.38 | 9.24 | 8.00 |
| | 134.00 | 22.45 | 18.06 | 14.53 | 11.83 | 9.75 | 8.13 |
| | 136.00 | 20.52 | 17.64 | 14.83 | 11.62 | 9.71 | 8.19 |
| | 138.00 | 18.50 | 16.37 | 13.74 | 11.55 | 9.77 | 8.32 |
| | 140.00 | 16.56 | 14.57 | 12.51 | 10.69 | 9.16 | 7.89 |
| 80.00 | 110.00 | 86.58 | 52.70 | 33.42 | 23.13 | 17.11 | 13.30 |
| | 112.00 | 84.54 | 53.46 | 36.09 | 26.37 | 20.38 | 16.41 |
| | 114.00 | 81.47 | 52.79 | 37.24 | 28.27 | 22.54 | 18.60 |
| | 116.00 | 77.97 | 52.11 | 38.29 | 30.04 | 24.58 | 20.70 |
| | 118.00 | 73.11 | 50.27 | 38.17 | 30.73 | 25.66 | 21.96 |
| | 120.00 | 67.61 | 48.34 | 37.91 | 31.27 | 26.58 | 23.88 |
| | 122.00 | 61.50 | 46.17 | 37.37 | 31.58 | 27.22 | 23.93 |
| | 124.00 | 56.87 | 44.69 | 37.35 | 32.15 | 28.20 | 25.08 |
| | 126.00 | 50.49 | 42.76 | 36.84 | 32.34 | 28.76 | 25.84 |
| | 128.00 | 44.71 | 40.17 | 35.64 | 31.87 | 28.71 | 26.15 |
| | 130.00 | 40.20 | 38.10 | 34.79 | 31.65 | 28.87 | 26.43 |
| | 132.00 | 35.26 | 36.30 | 33.80 | 30.90 | 28.22 | 26.90 |
| | 134.00 | 33.10 | 34.15 | 32.82 | 30.86 | 28.78 | 26.79 |
| | 136.00 | 30.17 | 32.14 | 31.62 | 30.19 | 28.47 | 26.72 |
| | 138.00 | 28.00 | 30.58 | 30.68 | 29.71 | 28.31 | 26.77 |
| | 140.00 | 24.66 | 27.78 | 28.53 | 28.18 | 27.10 | 25.86 |
| 120.00 | 110.00 | 90.82 | 65.11 | 47.99 | 37.53 | 33.71 | 25.97 |
| | 112.00 | 89.37 | 65.68 | 50.46 | 40.92 | 34.48 | 29.85 |
| | 114.00 | 87.14 | 65.84 | 51.46 | 42.82 | 36.84 | 32.43 |
| | 116.00 | 84.53 | 64.36 | 52.34 | 44.53 | 38.99 | 34.80 |
| | 118.00 | 80.79 | 62.66 | 52.12 | 45.15 | 40.08 | 36.17 |
| | 120.00 | 76.35 | 60.84 | 51.76 | 45.59 | 40.98 | 37.35 |
| | 122.00 | 71.08 | 58.72 | 51.11 | 45.73 | 41.58 | 38.23 |
| | 124.00 | 65.95 | 57.11 | 50.92 | 46.26 | 42.51 | 39.40 |
| | 126.00 | 60.27 | 55.04 | 50.25 | 46.31 | 43.00 | 40.15 |
| | 128.00 | 54.66 | 52.27 | 48.91 | 45.73 | 42.87 | 40.31 |
| | 130.00 | 48.81 | 49.89 | 47.86 | 45.38 | 42.94 | 40.65 |
| | 132.00 | 43.10 | 46.57 | 45.89 | 44.17 | 42.19 | 40.22 |
| | 134.00 | 40.13 | 45.07 | 45.41 | 44.27 | 42.65 | 40.90 |
| | 136.00 | 36.50 | 42.56 | 43.92 | 43.43 | 42.23 | 40.75 |
| | 138.00 | 33.73 | 40.46 | 42.67 | 42.77 | 41.94 | 40.73 |
| | 140.00 | 29.90 | 37.12 | 40.17 | 40.93 | 40.58 | 39.69 |

Table E -1-- continued

**% Retention**

| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| 160.00 | 110.00 | 93.03 | 72.43 | 57.59 | 47.88 | 41.19 | 36.33 |
| | 112.00 | 91.90 | 72.68 | 59.77 | 51.07 | 44.91 | 60.32 |
| | 114.00 | 90.16 | 72.10 | 60.63 | 52.81 | 47.19 | 42.90 |
| | 116.00 | 88.09 | 71.68 | 61.36 | 54.36 | 49.22 | 45.22 |
| | 118.00 | 85.07 | 70.19 | 61.12 | 54.89 | 50.22 | 46.53 |
| | 120.00 | 81.38 | 68.55 | 60.74 | 55.26 | 51.05 | 47.63 |
| | 122.00 | 76.86 | 68.62 | 60.09 | 55.34 | 51.58 | 48.47 |
| | 124.00 | 72.22 | 65.08 | 59.84 | 55.77 | 52.41 | 49.56 |
| | 126.00 | 66.83 | 63.09 | 59.15 | 55.76 | 52.83 | 50.24 |
| | 128.00 | 60.65 | 60.41 | 57.84 | 55.17 | 52.66 | 50.37 |
| | 130.00 | 55.09 | 58.01 | 56.75 | 54.77 | 52.68 | 50.66 |
| | 132.00 | 48.96 | 54.68 | 55.30 | 53.58 | 51.94 | 50.21 |
| | 134.00 | 45.43 | 52.95 | 54.22 | 53.59 | 52.32 | 50.82 |
| | 136.00 | 41.30 | 50.23 | 52.66 | 52.72 | 51.87 | 50.65 |
| | 138.00 | 38.07 | 47.85 | 51.30 | 52.00 | 51.54 | 50.58 |
| | 140.00 | 33.85 | 44.24 | 48.73 | 50.16 | 50.19 | 49.56 |
| 200.00 | 110.00 | 94.38 | 77.23 | 64.27 | 55.44 | 49.15 | 44.46 |
| | 112.00 | 93.46 | 77.60 | 66.20 | 58.36 | 52.67 | 48.32 |
| | 114.00 | 92.03 | 77.09 | 66.94 | 59.94 | 54.78 | 50.77 |
| | 116.00 | 90.31 | 76.53 | 67.56 | 61.33 | 56.65 | 52.94 |
| | 118.00 | 87.79 | 75.21 | 67.32 | 61.79 | 57.56 | 54.16 |
| | 120.00 | 84.60 | 73.75 | 66.95 | 62.09 | 58.38 | 55.19 |
| | 122.00 | 80.72 | 72.01 | 66.34 | 62.14 | 58.77 | 55.94 |
| | 124.00 | 76.55 | 70.58 | 66.07 | 62.90 | 59.51 | 56.93 |
| | 126.00 | 71.54 | 68.73 | 65.40 | 62.47 | 59.87 | 57.54 |
| | 128.00 | 65.57 | 68.23 | 64.17 | 61.89 | 59.69 | 57.64 |
| | 130.00 | 59.94 | 63.91 | 63.12 | 61.49 | 59.69 | 57.89 |
| | 132.00 | 53.61 | 60.69 | 61.29 | 60.37 | 58.98 | 57.47 |
| | 134.00 | 49.69 | 58.89 | 60.65 | 60.33 | 59.30 | 58.01 |
| | 136.00 | 45.19 | 56.11 | 59.12 | 59.48 | 58.85 | 57.82 |
| | 138.00 | 41.60 | 53.61 | 57.75 | 58.75 | 58.52 | 57.74 |
| | 140.00 | 37.00 | 49.68 | 55.23 | 56.99 | 57.23 | 56.78 |
| 240.00 | 110.00 | 95.29 | 80.61 | 69.16 | 61.14 | 55.31 | 50.87 |
| | 112.00 | 94.51 | 80.92 | 70.87 | 63.81 | 58.58 | 54.52 |
| | 114.00 | 93.30 | 80.47 | 71.52 | 65.24 | 60.52 | 56.81 |
| | 116.00 | 91.84 | 79.97 | 72.07 | 66.48 | 62.23 | 58.83 |
| | 118.00 | 89.67 | 78.79 | 71.84 | 66.89 | 63.08 | 59.95 |
| | 120.00 | 86.95 | 77.48 | 71.49 | 67.15 | 63.73 | 60.89 |
| | 122.00 | 83.49 | 75.91 | 70.92 | 67.18 | 64.14 | 61.57 |
| | 124.00 | 79.72 | 74.60 | 70.65 | 67.49 | 64.81 | 62.47 |
| | 126.00 | 75.08 | 72.89 | 70.02 | 67.44 | 65.12 | 63.03 |
| | 128.00 | 69.60 | 70.57 | 68.87 | 66.89 | 64.95 | 63.11 |
| | 130.00 | 63.83 | 68.38 | 67.89 | 66.51 | 64.93 | 63.33 |
| | 132.00 | 57.42 | 65.32 | 66.17 | 65.46 | 64.27 | 62.93 |
| | 134.00 | 53.23 | 63.51 | 65.53 | 65.39 | 64.54 | 63.41 |
| | 136.00 | 48.46 | 60.77 | 64.06 | 64.58 | 64.11 | 63.23 |
| | 138.00 | 44.58 | 58.24 | 62.72 | 63.88 | 63.78 | 63.14 |
| | 140.00 | 39.78 | 54.49 | 60.30 | 62.22 | 62.58 | 62.24 |

Table E 2 Simulated quality retention of foods with thermal diffusivity 1.4 x $10^{-7}$ $m^2/s$ after thermal processing in the conically shaped container #1 h = 300 w/m2K

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| **D (min)** | **Temp(°C)** | **Z = 10°C** | **Z = 20°C** | **Z = 30°C** | **Z = 40°C** | **Z = 50°C** | **Z = 60°C** |
| 40.00 | 110.00 | 76.47 | 30.69 | 13.54 | 6.96 | 4.04 | 2.56 |
| | 112.00 | 73.37 | 32.10 | 15.86 | 9.03 | 5.08 | 3.85 |
| | 114.00 | 66.69 | 31.59 | 16.93 | 10.33 | 6.87 | 4.86 |
| | 116.00 | 63.98 | 31.02 | 17.88 | 11.56 | 8.05 | 5.91 |
| | 118.00 | 57.73 | 29.99 | 18.39 | 12.46 | 9.00 | 6.80 |
| | 120.00 | 51.91 | 29.04 | 18.66 | 13.33 | 9.93 | 7.69 |
| | 122.00 | 46.23 | 27.93 | 19.13 | 14.01 | 10.73 | 8.49 |
| | 124.00 | 40.66 | 26.56 | 19.00 | 14.36 | 11.26 | 9.07 |
| | 126.00 | 35.05 | 24.55 | 18.29 | 14.21 | 11.36 | 9.29 |
| | 128.00 | 30.86 | 23.16 | 17.92 | 14.29 | 11.64 | 9.66 |
| | 130.00 | 28.30 | 21.70 | 17.02 | 14.62 | 12.12 | 10.20 |
| | 132.00 | 24.89 | 20.65 | 17.05 | 14.21 | 11.98 | 10.20 |
| | 134.00 | 22.42 | 19.37 | 16.44 | 13.97 | 11.95 | 10.30 |
| | 136.00 | 20.72 | 18.51 | 16.08 | 13.90 | 12.04 | 10.48 |
| | 138.00 | 19.68 | 18.04 | 15.87 | 14.01 | 12.27 | 10.78 |
| | 140.00 | 17.83 | 16.72 | 15.66 | 13.42 | 11.89 | 10.54 |
| 80.00 | 110.00 | 87.39 | 55.24 | 36.41 | 26.66 | 19.86 | 15.83 |
| | 112.00 | 85.53 | 56.14 | 39.28 | 29.59 | 23.50 | 19.36 |
| | 114.00 | 82.61 | 55.46 | 40.41 | 31.54 | 25.76 | 21.72 |
| | 116.00 | 79.20 | 54.64 | 41.32 | 33.24 | 27.81 | 23.89 |
| | 118.00 | 74.03 | 53.30 | 41.65 | 34.37 | 29.31 | 25.56 |
| | 120.00 | 70.56 | 51.93 | 41.89 | 35.36 | 30.68 | 27.12 |
| | 122.00 | 64.83 | 50.34 | 41.85 | 36.07 | 31.77 | 28.41 |
| | 124.00 | 58.87 | 48.28 | 41.31 | 36.29 | 32.40 | 29.20 |
| | 126.00 | 52.23 | 45.50 | 40.07 | 35.83 | 32.39 | 29.53 |
| | 128.00 | 46.62 | 43.22 | 39.18 | 35.65 | 32.62 | 30.01 |
| | 130.00 | 42.33 | 41.50 | 38.67 | 35.78 | 33.11 | 30.71 |
| | 132.00 | 37.45 | 38.72 | 37.12 | 34.93 | 32.69 | 30.58 |
| | 134.00 | 33.68 | 36.40 | 35.85 | 34.28 | 32.44 | 30.59 |
| | 136.00 | 30.90 | 34.56 | 34.85 | 33.84 | 32.34 | 30.71 |
| | 138.00 | 28.97 | 33.21 | 34.15 | 33.61 | 32.43 | 31.01 |
| | 140.00 | 26.25 | 30.89 | 32.47 | 32.44 | 32.63 | 30.47 |
| 120.00 | 110.00 | 91.39 | 67.23 | 50.87 | 40.68 | 33.94 | 29.19 |
| | 112.00 | 90.08 | 67.91 | 53.46 | 44.25 | 37.95 | 33.56 |
| | 114.00 | 87.98 | 67.29 | 54.43 | 46.13 | 40.33 | 36.01 |
| | 116.00 | 85.46 | 66.53 | 55.17 | 47.74 | 42.40 | 38.35 |
| | 118.00 | 82.22 | 65.31 | 55.38 | 48.75 | 43.88 | 40.89 |
| | 120.00 | 78.43 | 64.01 | 55.49 | 49.62 | 45.20 | 41.67 |
| | 122.00 | 73.94 | 62.48 | 55.33 | 50.21 | 46.21 | 42.96 |
| | 124.00 | 68.59 | 60.48 | 54.71 | 50.33 | 46.77 | 43.79 |
| | 126.00 | 62.21 | 57.76 | 53.43 | 49.80 | 46.70 | 44.01 |
| | 128.00 | 56.28 | 55.37 | 52.44 | 49.53 | 46.66 | 44.44 |
| | 130.00 | 51.30 | 53.40 | 51.77 | 49.53 | 47.25 | 45.09 |
| | 132.00 | 45.68 | 50.38 | 50.10 | 48.60 | 46.77 | 44.91 |
| | 134.00 | 41.11 | 47.69 | 48.64 | 47.84 | 46.44 | 44.86 |
| | 136.00 | 37.60 | 45.40 | 47.42 | 47.25 | 46.25 | 44.91 |
| | 138.00 | 35.03 | 43.54 | 46.45 | 46.87 | 46.24 | 45.14 |
| | 140.00 | 31.74 | 40.72 | 44.50 | 45.56 | 45.34 | 44.54 |

Table E- 2 — continued

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| **D (min)** | **Temp(°C)** | **Z = 10°C** | **Z = 20°C** | **Z = 30°C** | **Z = 40°C** | **Z = 50°C** | **Z = 60°C** |
| 160.00 | 110.00 | 93.47 | 74.21 | 60.16 | 56.89 | 44.42 | 39.68 |
| | 112.00 | 92.45 | 74.75 | 62.44 | 54.18 | 48.29 | 43.85 |
| | 114.00 | 90.82 | 74.20 | 63.26 | 55.89 | 50.53 | 46.42 |
| | 116.00 | 88.83 | 73.54 | 63.88 | 57.31 | 52.45 | 48.65 |
| | 118.00 | 86.23 | 72.46 | 64.03 | 58.20 | 53.88 | 50.29 |
| | 120.00 | 83.12 | 71.31 | 64.07 | 58.95 | 54.99 | 51.76 |
| | 122.00 | 79.32 | 69.92 | 63.88 | 59.43 | 55.89 | 52.94 |
| | 124.00 | 74.62 | 68.16 | 63.27 | 59.50 | 56.37 | 53.69 |
| | 126.00 | 68.75 | 65.61 | 62.07 | 58.99 | 56.27 | 53.87 |
| | 128.00 | 62.95 | 63.34 | 61.10 | 58.69 | 56.38 | 54.25 |
| | 130.00 | 57.75 | 61.38 | 60.41 | 58.63 | 56.71 | 54.82 |
| | 132.00 | 51.76 | 58.41 | 58.80 | 57.73 | 56.24 | 54.63 |
| | 134.00 | 46.71 | 55.66 | 57.35 | 56.97 | 55.69 | 54.55 |
| | 136.00 | 42.67 | 53.20 | 56.05 | 56.36 | 55.67 | 54.57 |
| | 136.00 | 39.61 | 51.10 | 55.04 | 55.93 | 55.61 | 54.75 |
| | 140.00 | 35.89 | 48.05 | 53.06 | 54.63 | 54.73 | 54.17 |
| 200.00 | 110.00 | 94.74 | 76.75 | 66.58 | 58.22 | 52.22 | 47.71 |
| | 112.00 | 93.91 | 79.20 | 66.57 | 61.21 | 55.82 | 51.68 |
| | 114.00 | 92.57 | 78.72 | 69.28 | 62.73 | 57.88 | 54.09 |
| | 116.00 | 90.93 | 79.13 | 69.80 | 64.00 | 59.63 | 56.15 |
| | 118.00 | 88.77 | 77.19 | 69.90 | 64.77 | 60.84 | 57.85 |
| | 120.00 | 86.14 | 76.16 | 69.92 | 65.43 | 61.90 | 56.99 |
| | 122.00 | 82.87 | 74.92 | 69.72 | 65.84 | 62.70 | 60.05 |
| | 124.00 | 78.71 | 73.28 | 69.16 | 65.88 | 63.12 | 60.73 |
| | 126.00 | 73.38 | 71.03 | 68.00 | 65.39 | 63.01 | 60.88 |
| | 128.00 | 67.66 | 68.93 | 67.15 | 65.10 | 63.10 | 61.21 |
| | 130.00 | 62.65 | 67.07 | 66.47 | 65.02 | 63.37 | 61.71 |
| | 132.00 | 56.53 | 64.24 | 64.97 | 64.16 | 62.92 | 61.52 |
| | 134.00 | 51.17 | 61.56 | 63.59 | 63.45 | 62.58 | 61.44 |
| | 136.00 | 46.76 | 59.09 | 62.37 | 62.86 | 62.36 | 61.44 |
| | 138.00 | 43.33 | 56.98 | 61.32 | 62.42 | 62.27 | 61.59 |
| | 140.00 | 39.27 | 53.77 | 59.39 | 61.19 | 61.45 | 61.03 |
| 240.00 | 110.00 | 95.59 | 81.54 | 71.23 | 63.69 | 56.16 | 53.96 |
| | 112.00 | 94.89 | 82.32 | 72.99 | 66.40 | 61.50 | 57.67 |
| | 114.00 | 93.76 | 81.90 | 73.61 | 67.77 | 63.37 | 59.90 |
| | 116.00 | 92.37 | 81.37 | 74.07 | 68.90 | 64.96 | 61.88 |
| | 118.00 | 90.52 | 80.54 | 74.15 | 69.59 | 66.05 | 63.16 |
| | 120.00 | 88.24 | 79.62 | 74.15 | 70.16 | 67.01 | 64.38 |
| | 122.00 | 85.38 | 78.50 | 73.95 | 70.52 | 67.72 | 65.34 |
| | 124.00 | 81.67 | 77.02 | 73.43 | 70.54 | 68.09 | 65.95 |
| | 126.00 | 76.81 | 74.99 | 72.43 | 70.09 | 67.98 | 66.07 |
| | 128.00 | 71.62 | 73.06 | 71.59 | 69.81 | 68.05 | 66.36 |
| | 130.00 | 66.52 | 71.31 | 70.95 | 69.72 | 68.28 | 66.61 |
| | 132.00 | 60.40 | 68.66 | 69.56 | 68.94 | 67.86 | 66.63 |
| | 134.00 | 54.96 | 66.09 | 68.27 | 68.26 | 67.54 | 66.55 |
| | 136.00 | 50.19 | 63.68 | 67.10 | 67.70 | 67.32 | 66.54 |
| | 138.00 | 46.46 | 61.48 | 66.08 | 67.27 | 67.23 | 66.66 |
| | 140.00 | 42.23 | 58.36 | 64.25 | 66.12 | 66.47 | 66.15 |

Table E-3 Simulated quality retention of foods with thermal diffusivity $1.6 \times 10^{-7}$ m$^2$/s after thermal processing in the conically shaped container #1 h = 300 w/m2K

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| D (mm) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 40.00 | 110.00 | 77.36 | 32.81 | 15.15 | 8.16 | 4.93 | 3.25 |
| | 112.00 | 74.37 | 34.07 | 17.65 | 10.48 | 6.85 | 4.80 |
| | 114.00 | 70.30 | 34.11 | 19.21 | 12.23 | 8.45 | 6.18 |
| | 116.00 | 65.56 | 33.73 | 20.38 | 13.72 | 9.90 | 7.49 |
| | 118.00 | 59.66 | 33.60 | 20.96 | 14.76 | 11.22 | 8.57 |
| | 120.00 | 54.83 | 32.33 | 21.95 | 16.11 | 12.40 | 9.88 |
| | 122.00 | 48.28 | 31.80 | 21.66 | 16.44 | 12.97 | 10.53 |
| | 124.00 | 42.41 | 29.70 | 22.00 | 16.73 | 13.49 | 11.13 |
| | 126.00 | 37.02 | 28.50 | 21.30 | 16.82 | 13.83 | 11.60 |
| | 128.00 | 34.12 | 26.80 | 21.52 | 17.69 | 14.81 | 12.59 |
| | 130.00 | 29.70 | 24.72 | 20.54 | 17.27 | 14.70 | 12.65 |
| | 132.00 | 26.48 | 23.17 | 19.85 | 17.05 | 14.73 | 12.83 |
| | 134.00 | 24.27 | 22.11 | 19.46 | 17.03 | 14.93 | 13.14 |
| | 136.00 | 22.93 | 21.54 | 19.38 | 17.23 | 15.29 | 13.59 |
| | 138.00 | 19.89 | 19.42 | 17.93 | 16.24 | 14.61 | 13.13 |
| | 140.00 | 19.84 | 19.64 | 18.37 | 16.81 | 15.25 | 13.79 |
| 80.00 | 110.00 | 87.91 | 57.02 | 38.61 | 28.30 | 22.01 | 17.87 |
| | 112.00 | 86.15 | 57.97 | 41.57 | 32.00 | 25.89 | 21.69 |
| | 114.00 | 83.64 | 57.81 | 43.23 | 34.48 | 28.69 | 24.58 |
| | 116.00 | 80.55 | 57.23 | 44.35 | 36.41 | 30.98 | 27.02 |
| | 118.00 | 76.54 | 55.99 | 45.30 | 37.63 | 32.61 | 28.84 |
| | 120.00 | 72.53 | 55.25 | 45.56 | 39.16 | 34.50 | 30.91 |
| | 122.00 | 66.85 | 53.11 | 44.95 | 39.38 | 35.17 | 31.83 |
| | 124.00 | 60.95 | 51.00 | 44.38 | 39.53 | 35.74 | 32.65 |
| | 126.00 | 54.74 | 48.64 | 43.51 | 39.42 | 36.06 | 33.23 |
| | 128.00 | 50.31 | 47.50 | 43.66 | 40.20 | 37.18 | 34.54 |
| | 130.00 | 44.41 | 44.58 | 42.14 | 39.43 | 36.86 | 34.51 |
| | 132.00 | 39.69 | 42.09 | 40.89 | 38.87 | 36.72 | 34.64 |
| | 134.00 | 36.14 | 40.08 | 39.94 | 38.54 | 36.77 | 34.93 |
| | 136.00 | 33.65 | 38.57 | 39.31 | 38.46 | 37.82 | 35.40 |
| | 138.00 | 30.30 | 35.41 | 37.09 | 36.91 | 35.93 | 34.62 |
| | 140.00 | 28.81 | 34.85 | 37.05 | 37.25 | 36.52 | 35.37 |
| 128.00 | 110.00 | 91.76 | 68.69 | 52.93 | 43.01 | 36.38 | 31.66 |
| | 112.00 | 90.51 | 69.41 | 55.56 | 46.66 | 40.52 | 36.01 |
| | 114.00 | 88.72 | 69.23 | 56.99 | 49.01 | 43.37 | 39.13 |
| | 116.00 | 86.47 | 68.69 | 57.92 | 50.78 | 45.63 | 41.67 |
| | 118.00 | 83.46 | 67.59 | 58.20 | 51.86 | 47.18 | 43.50 |
| | 120.00 | 80.31 | 66.86 | 58.81 | 53.21 | 48.95 | 45.53 |
| | 122.00 | 75.66 | 64.93 | 58.21 | 53.35 | 49.54 | 46.41 |
| | 124.00 | 70.54 | 62.97 | 57.57 | 53.42 | 50.03 | 47.17 |
| | 126.00 | 64.70 | 60.71 | 56.67 | 53.24 | 50.28 | 47.70 |
| | 128.00 | 59.98 | 59.41 | 56.64 | 53.85 | 51.27 | 48.91 |
| | 130.00 | 53.66 | 56.48 | 55.11 | 53.05 | 50.92 | 48.84 |
| | 132.00 | 48.24 | 53.83 | 53.79 | 52.43 | 50.71 | 48.92 |
| | 134.00 | 43.90 | 51.52 | 52.70 | 52.01 | 50.68 | 49.15 |
| | 136.00 | 40.67 | 49.62 | 51.88 | 51.80 | 50.84 | 49.54 |
| | 138.00 | 36.01 | 46.10 | 49.56 | 50.21 | 49.73 | 48.75 |
| | 140.00 | 34.60 | 45.04 | 49.23 | 50.38 | 50.19 | 49.40 |

Table E- 3 -- continued

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 160.00 | 110.00 | 93.75 | 75.43 | 62.81 | 53.07 | 46.80 | 42.18 |
| | 112.00 | 92.79 | 76.00 | 64.29 | 56.40 | 50.73 | 46.45 |
| | 114.00 | 91.40 | 75.63 | 65.51 | 58.50 | 53.38 | 49.43 |
| | 116.00 | 89.63 | 75.35 | 66.28 | 60.07 | 55.44 | 51.80 |
| | 118.00 | 87.23 | 74.40 | 66.49 | 61.50 | 56.83 | 53.49 |
| | 120.00 | 84.67 | 73.73 | 66.98 | 62.16 | 58.41 | 55.34 |
| | 122.00 | 80.81 | 72.05 | 66.42 | 62.26 | 58.92 | 56.13 |
| | 124.00 | 76.37 | 70.31 | 65.82 | 62.29 | 59.34 | 56.61 |
| | 126.00 | 71.09 | 68.26 | 64.97 | 62.09 | 59.54 | 57.27 |
| | 128.00 | 66.49 | 66.99 | 64.88 | 62.59 | 60.39 | 58.34 |
| | 130.00 | 60.19 | 64.26 | 63.46 | 61.63 | 60.04 | 58.26 |
| | 132.00 | 54.48 | 61.69 | 62.20 | 61.23 | 59.83 | 58.31 |
| | 134.00 | 49.68 | 59.37 | 61.13 | 60.80 | 59.77 | 58.49 |
| | 136.00 | 45.93 | 57.36 | 60.28 | 60.55 | 59.87 | 58.82 |
| | 138.00 | 40.82 | 53.78 | 58.04 | 59.06 | 58.84 | 56.08 |
| | 140.00 | 38.97 | 52.44 | 57.60 | 59.13 | 59.21 | 58.64 |
| 200.00 | 110.00 | 94.97 | 79.79 | 68.21 | 60.22 | 54.46 | 50.11 |
| | 112.00 | 94.16 | 80.27 | 70.20 | 63.21 | 56.08 | 54.13 |
| | 114.00 | 93.05 | 80.11 | 71.25 | 65.08 | 60.49 | 56.88 |
| | 116.00 | 91.59 | 79.69 | 71.91 | 66.66 | 62.34 | 59.05 |
| | 118.00 | 89.60 | 78.86 | 72.07 | 67.28 | 63.58 | 60.58 |
| | 120.00 | 87.45 | 78.26 | 72.46 | 68.29 | 64.98 | 62.25 |
| | 122.00 | 84.36 | 76.79 | 71.96 | 68.35 | 65.43 | 62.95 |
| | 124.00 | 80.26 | 75.24 | 71.41 | 68.36 | 65.79 | 63.55 |
| | 126.00 | 75.53 | 73.40 | 70.65 | 68.17 | 65.95 | 63.95 |
| | 128.00 | 71.18 | 72.21 | 70.52 | 66.56 | 66.69 | 64.90 |
| | 130.00 | 65.39 | 69.71 | 69.23 | 67.90 | 66.37 | 64.82 |
| | 132.00 | 59.31 | 67.30 | 68.86 | 67.34 | 66.16 | 64.85 |
| | 134.00 | 54.25 | 65.06 | 67.65 | 66.92 | 66.09 | 65.00 |
| | 136.00 | 50.15 | 63.06 | 66.22 | 66.66 | 66.16 | 65.26 |
| | 138.00 | 44.72 | 59.56 | 64.13 | 65.29 | 65.21 | 64.61 |
| | 140.00 | 42.49 | 58.09 | 63.64 | 65.32 | 65.52 | 65.09 |
| 240.00 | 110.00 | 95.79 | 82.84 | 72.68 | 65.51 | 60.25 | 56.21 |
| | 112.00 | 95.13 | 83.25 | 74.45 | 68.22 | 63.57 | 59.94 |
| | 114.00 | 94.17 | 83.11 | 75.37 | 69.89 | 65.75 | 62.47 |
| | 116.00 | 92.93 | 82.73 | 75.94 | 71.12 | 67.42 | 64.45 |
| | 118.00 | 91.23 | 82.00 | 76.07 | 71.88 | 68.54 | 65.84 |
| | 120.00 | 89.38 | 81.66 | 76.42 | 72.73 | 69.79 | 67.34 |
| | 122.00 | 86.51 | 80.16 | 75.95 | 72.76 | 70.16 | 67.96 |
| | 124.00 | 83.08 | 78.77 | 75.45 | 72.77 | 70.50 | 68.50 |
| | 126.00 | 78.79 | 77.12 | 74.75 | 72.59 | 70.63 | 68.86 |
| | 128.00 | 74.72 | 76.02 | 74.62 | 72.94 | 71.28 | 69.70 |
| | 130.00 | 68.92 | 73.73 | 73.44 | 72.32 | 70.99 | 69.62 |
| | 132.00 | 63.19 | 71.50 | 72.37 | 71.00 | 70.79 | 69.64 |
| | 134.00 | 57.99 | 69.37 | 71.43 | 71.40 | 70.71 | 69.77 |
| | 136.00 | 53.65 | 67.43 | 70.64 | 71.15 | 70.76 | 70.01 |
| | 138.00 | 56.00 | 64.08 | 68.70 | 69.90 | 69.90 | 69.40 |
| | 140.00 | 45.47 | 62.55 | 66.20 | 69.89 | 70.16 | 69.82 |

Table E- 4 Simulated quality retention of foods with thermal diffusivity 1.2 x $10^{-7}$ $m^2$ /s after thermal processing in the conically shaped container #1 using Infinite h

| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| | | % Retention | | | | | |
| 40.00 | 110.00 | 74.51 | 28.28 | 11.80 | 5.82 | 3.26 | 2.01 |
| | 112.00 | 78.17 | 28.41 | 13.28 | 7.23 | 4.38 | 2.87 |
| | 114.00 | 84.99 | 28.02 | 14.35 | 8.43 | 5.43 | 3.74 |
| | 116.00 | 59.64 | 27.76 | 15.45 | 9.68 | 6.56 | 4.70 |
| | 118.00 | 53.03 | 26.44 | 15.69 | 10.33 | 7.26 | 5.36 |
| | 120.00 | 46.71 | 25.22 | 15.88 | 10.91 | 7.93 | 6.01 |
| | 122.00 | 40.84 | 23.95 | 15.89 | 11.33 | 8.47 | 6.55 |
| | 124.00 | 35.42 | 22.42 | 15.57 | 11.47 | 8.78 | 6.92 |
| | 126.00 | 30.23 | 20.45 | 15.50 | 11.00 | 8.76 | 7.03 |
| | 128.00 | 26.80 | 19.40 | 15.21 | 11.83 | 9.44 | 7.69 |
| | 130.00 | 24.04 | 18.19 | 14.11 | 11.23 | 9.12 | 7.52 |
| | 132.00 | 22.62 | 17.86 | 14.24 | 11.56 | 9.53 | 7.97 |
| | 134.00 | 20.39 | 16.66 | 13.63 | 11.27 | 9.43 | 7.98 |
| | 136.00 | 18.81 | 15.84 | 13.23 | 11.13 | 9.43 | 8.06 |
| | 138.00 | 17.77 | 15.34 | 13.05 | 11.13 | 9.53 | 8.23 |
| | 140.00 | 15.43 | 13.75 | 11.94 | 10.33 | 8.95 | 7.81 |
| 80.00 | 110.00 | 86.22 | 52.65 | 33.78 | 23.68 | 17.74 | 13.94 |
| | 112.00 | 83.55 | 52.52 | 35.65 | 26.27 | 20.48 | 16.63 |
| | 114.00 | 80.14 | 51.80 | 36.83 | 28.23 | 22.72 | 18.91 |
| | 116.00 | 76.28 | 51.09 | 37.93 | 30.08 | 24.86 | 21.12 |
| | 118.00 | 71.04 | 49.25 | 37.87 | 30.86 | 26.03 | 22.48 |
| | 120.00 | 65.24 | 47.37 | 37.70 | 31.48 | 27.06 | 23.71 |
| | 122.00 | 59.01 | 45.28 | 37.26 | 31.82 | 27.79 | 24.65 |
| | 124.00 | 52.49 | 42.81 | 36.37 | 31.71 | 28.12 | 25.23 |
| | 126.00 | 45.75 | 39.75 | 34.85 | 31.20 | 27.88 | 25.80 |
| | 128.00 | 41.76 | 38.50 | 34.80 | 31.55 | 28.75 | 26.33 |
| | 130.00 | 36.18 | 35.25 | 32.84 | 30.33 | 27.99 | 25.87 |
| | 132.00 | 33.39 | 33.88 | 32.38 | 30.42 | 28.40 | 26.48 |
| | 134.00 | 30.06 | 31.62 | 30.99 | 29.80 | 27.97 | 26.31 |
| | 136.00 | 27.59 | 29.82 | 29.88 | 28.99 | 27.69 | 26.27 |
| | 138.00 | 25.83 | 28.48 | 29.05 | 28.57 | 27.57 | 26.35 |
| | 140.00 | 22.90 | 25.94 | 27.03 | 27.02 | 26.38 | 25.43 |
| 120.00 | 110.00 | 90.56 | 65.05 | 48.32 | 38.11 | 31.44 | 26.78 |
| | 112.00 | 88.65 | 64.87 | 50.82 | 40.79 | 34.57 | 30.10 |
| | 114.00 | 86.16 | 64.16 | 51.04 | 42.75 | 37.01 | 32.78 |
| | 116.00 | 83.23 | 63.42 | 51.95 | 44.53 | 39.25 | 35.25 |
| | 118.00 | 79.11 | 61.69 | 51.77 | 45.21 | 40.43 | 36.72 |
| | 120.00 | 74.27 | 59.84 | 51.46 | 45.73 | 41.42 | 38.00 |
| | 122.00 | 68.08 | 57.73 | 50.87 | 45.95 | 42.11 | 38.96 |
| | 124.00 | 62.37 | 55.17 | 49.84 | 45.72 | 42.36 | 39.52 |
| | 126.00 | 55.40 | 51.97 | 48.19 | 44.89 | 42.03 | 39.52 |
| | 128.00 | 50.62 | 50.32 | 47.88 | 45.28 | 42.81 | 40.55 |
| | 130.00 | 44.25 | 46.71 | 45.71 | 43.91 | 41.94 | 40.01 |
| | 132.00 | 40.54 | 44.82 | 44.95 | 43.81 | 42.24 | 40.56 |
| | 134.00 | 36.43 | 43.02 | 43.26 | 42.81 | 41.69 | 40.31 |
| | 136.00 | 33.38 | 39.66 | 41.80 | 41.98 | 41.28 | 40.18 |
| | 138.00 | 31.00 | 37.74 | 40.60 | 41.34 | 41.01 | 40.18 |
| | 140.00 | 27.64 | 34.63 | 38.18 | 39.52 | 39.64 | 39.12 |

Table E- 4 --continued

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 160.00 | 110.00 | 92.83 | 72.37 | 57.87 | 48.42 | 41.92 | 37.17 |
| | 112.00 | 91.34 | 72.18 | 59.36 | 50.94 | 45.00 | 40.57 |
| | 114.00 | 89.38 | 71.54 | 63.23 | 52.73 | 47.34 | 43.23 |
| | 116.00 | 87.04 | 70.86 | 60.98 | 54.34 | 49.45 | 45.65 |
| | 118.00 | 83.68 | 69.31 | 60.76 | 54.92 | 50.54 | 47.05 |
| | 120.00 | 79.60 | 67.62 | 60.42 | 55.35 | 51.44 | 48.26 |
| | 122.00 | 74.68 | 65.65 | 59.81 | 55.50 | 52.04 | 49.15 |
| | 124.00 | 68.85 | 63.24 | 58.80 | 55.23 | 52.24 | 49.65 |
| | 126.00 | 62.09 | 60.18 | 57.19 | 54.40 | 51.89 | 49.61 |
| | 128.00 | 57.00 | 58.43 | 56.78 | 54.68 | 52.57 | 50.55 |
| | 130.00 | 50.27 | 54.83 | 54.65 | 53.34 | 51.71 | 50.01 |
| | 132.00 | 45.97 | 52.72 | 53.78 | 53.15 | 51.93 | 50.50 |
| | 134.00 | 41,29 | 49.71 | 52,02 | 52.12 | 51.35 | 50.22 |
| | 136.00 | 37.64 | 47.05 | 50.44 | 51.23 | 50.89 | 50.05 |
| | 138.00 | 34.90 | 44.78 | 49.09 | 50.50 | 50.57 | 50.00 |
| | 140.00 | 31.20 | 41.34 | 46.53 | 48.65 | 49.20 | 48.96 |
| 200.00 | 110.00 | 94.21 | 77.18 | 64.51 | 55.94 | 49.84 | 45.28 |
| | 112.00 | 93.00 | 77.00 | 65.82 | 58.24 | 52.74 | 48.55 |
| | 114.00 | 91.39 | 76.42 | 66.57 | 59.85 | 54.92 | 51.08 |
| | 116.00 | 89.44 | 75.81 | 67.21 | 61.29 | 56.86 | 53.34 |
| | 118.00 | 86.61 | 74.42 | 66.99 | 61.80 | 57.83 | 54.63 |
| | 120.00 | 83.18 | 72.90 | 66.64 | 62.16 | 58.65 | 55.74 |
| | 122.00 | 78.76 | 71.11 | 66.00 | 62.26 | 59.17 | 56.55 |
| | 124.00 | 73.43 | 68.89 | 65.10 | 61.99 | 59.33 | 57.00 |
| | 126.00 | 67.02 | 66.04 | 63.59 | 61.20 | 58.99 | 56.95 |
| | 128.00 | 61.87 | 64.31 | 63.14 | 61.41 | 59.58 | 57.80 |
| | 130.00 | 55.01 | 60.84 | 61.13 | 60.14 | 58.77 | 57.28 |
| | 132.00 | 50.33 | 58.67 | 60.24 | 59.92 | 58.94 | 57.71 |
| | 134.00 | 45.25 | 55.61 | 58.51 | 58.91 | 58.37 | 57.43 |
| | 136.00 | 41.19 | 52.82 | 56.93 | 58.03 | 57.91 | 57.25 |
| | 138.00 | 38.07 | 50.37 | 55.52 | 57.28 | 57.57 | 57.18 |
| | 140.00 | 34.08 | 46.75 | 52.96 | 55.48 | 56.26 | 56.18 |
| 240.00 | 110.00 | 95.15 | 80.56 | 69.38 | 61.60 | 55.93 | 51.65 |
| | 112.00 | 94.13 | 80.40 | 70.54 | 63.69 | 58.65 | 54.74 |
| | 114.00 | 92.76 | 79.88 | 71.19 | 65.15 | 60.65 | 57.10 |
| | 116.00 | 91.09 | 79.32 | 71.75 | 66.45 | 62.42 | 59.19 |
| | 118.00 | 88.65 | 78.09 | 71.53 | 66.89 | 63.31 | 60.38 |
| | 120.00 | 85.58 | 76.71 | 71.20 | 67.20 | 64.07 | 61.39 |
| | 122.00 | 81.71 | 75.08 | 70.65 | 67.27 | 64.50 | 62.13 |
| | 124.00 | 76.84 | 73.04 | 69.75 | 67.01 | 64.63 | 62.53 |
| | 126.00 | 70.82 | 70.41 | 68.36 | 66.27 | 64.31 | 62.48 |
| | 128.00 | 65.73 | 68.74 | 67.90 | 66.43 | 64.83 | 63.24 |
| | 130.00 | 58.68 | 65.47 | 66.02 | 65.25 | 64.07 | 62.76 |
| | 132.00 | 53.96 | 63.32 | 65.15 | 65.01 | 64.20 | 63.13 |
| | 134.00 | 48.80 | 60.29 | 63.49 | 64.06 | 63.66 | 62.86 |
| | 136.00 | 44.20 | 57.47 | 61.94 | 63.20 | 63.22 | 62.68 |
| | 138.00 | 40.77 | 54.92 | 60.54 | 62.47 | 62.88 | 62.60 |
| | 140.00 | 36.52 | 51.22 | 58.05 | 60.75 | 61.64 | 61.67 |

Table E- 5 Simulated quality retention of foods with thermal diffusivity 1.4 x $10^{-7}$ $m^2/s$ after thermal processing in the conically shaped container #1 using Infinite h

**% Retention**

| **D (min)** | **Temp(°C)** | **Z = 10°C** | **Z = 20°C** | **Z = 30°C** | **Z = 40°C** | **Z = 50°C** | **Z = 60°C** |
|---|---|---|---|---|---|---|---|
| 40.00 | 110.00 | 75.76 | 30.76 | 13.78 | 7.25 | 4.30 | 2.79 |
| | 112.00 | 72.07 | 31.52 | 15.86 | 9.21 | 5.91 | 4.07 |
| | 114.00 | 67.10 | 31.10 | 17.04 | 10.63 | 7.22 | 5.20 |
| | 116.00 | 61.78 | 30.69 | 18.15 | 12.01 | 8.54 | 6.38 |
| | 118.00 | 55.86 | 29.86 | 18.04 | 13.09 | 9.66 | 7.43 |
| | 120.00 | 48.96 | 29.09 | 18.70 | 13.50 | 10.26 | 8.07 |
| | 122.00 | 42.10 | 26.06 | 18.21 | 13.60 | 10.60 | 8.51 |
| | 124.00 | 36.90 | 24.80 | 18.16 | 14.01 | 11.17 | 9.13 |
| | 126.00 | 31.84 | 23.01 | 17.56 | 13.92 | 11.33 | 9.41 |
| | 128.00 | 28.37 | 21.85 | 17.32 | 14.09 | 11.69 | 9.85 |
| | 130.00 | 26.29 | 21.32 | 17.46 | 14.52 | 12.25 | 10.46 |
| | 132.00 | 23.48 | 19.87 | 16.74 | 14.21 | 12.18 | 10.53 |
| | 134.00 | 21.52 | 18.07 | 16.29 | 14.08 | 12.22 | 10.67 |
| | 136.00 | 20.29 | 18.28 | 16.10 | 14.14 | 12.42 | 10.95 |
| | 138.00 | 17.62 | 16.43 | 14.80 | 13.21 | 11.77 | 10.49 |
| | 140.00 | 17.46 | 16.52 | 15.07 | 13.59 | 12.21 | 10.97 |
| 80.00 | 110.00 | 86.97 | 55.05 | 36.67 | 26.56 | 20.47 | 16.49 |
| | 112.00 | 84.72 | 55.53 | 39.18 | 29.03 | 23.94 | 19.90 |
| | 114.00 | 81.55 | 54.86 | 40.42 | 31.92 | 26.36 | 22.44 |
| | 116.00 | 77.85 | 54.10 | 41.47 | 33.78 | 28.57 | 24.78 |
| | 118.00 | 73.31 | 52.86 | 41.95 | 35.09 | 30.27 | 26.67 |
| | 120.00 | 67.40 | 50.62 | 41.43 | 35.42 | 31.07 | 27.72 |
| | 122.00 | 60.65 | 47.95 | 40.46 | 35.31 | 31.43 | 28.36 |
| | 124.00 | 54.49 | 45.87 | 39.95 | 35.57 | 32.10 | 29.27 |
| | 126.00 | 47.98 | 43.13 | 38.75 | 35.16 | 32.16 | 29.60 |
| | 128.00 | 42.76 | 40.95 | 37.92 | 35.04 | 32.45 | 30.16 |
| | 130.00 | 39.00 | 39.38 | 37.51 | 35.26 | 33.03 | 30.95 |
| | 132.00 | 34.75 | 36.02 | 36.07 | 34.49 | 32.69 | 30.89 |
| | 134.00 | 31.61 | 34.76 | 34.91 | 33.92 | 32.50 | 30.94 |
| | 136.00 | 27.42 | 33.20 | 34.07 | 33.59 | 32.51 | 31.10 |
| | 138.00 | 25.98 | 30.29 | 31.88 | 31.98 | 31.32 | 30.31 |
| | 140.00 | 25.19 | 29.64 | 31.60 | 32.05 | 31.65 | 30.82 |
| 120.00 | 110.00 | 91.09 | 67.06 | 51.06 | 41.19 | 34.62 | 29.99 |
| | 112.00 | 89.50 | 67.38 | 53.34 | 44.47 | 38.40 | 33.97 |
| | 114.00 | 87.20 | 66.75 | 54.39 | 46.47 | 40.93 | 36.78 |
| | 116.00 | 84.44 | 66.02 | 55.25 | 48.21 | 43.15 | 39.28 |
| | 118.00 | 80.91 | 64.84 | 55.58 | 49.38 | 44.81 | 41.22 |
| | 120.00 | 76.12 | 62.77 | 54.99 | 49.62 | 45.54 | 42.26 |
| | 122.00 | 70.27 | 60.25 | 53.97 | 49.42 | 45.84 | 42.88 |
| | 124.00 | 64.41 | 58.13 | 53.33 | 49.56 | 46.42 | 43.74 |
| | 126.00 | 57.79 | 55.33 | 52.04 | 49.06 | 46.40 | 44.03 |
| | 128.00 | 51.96 | 52.91 | 51.05 | 48.82 | 46.61 | 44.53 |
| | 130.00 | 47.32 | 50.97 | 50.42 | 48.88 | 47.08 | 45.26 |
| | 132.00 | 42.22 | 48.03 | 48.79 | 47.99 | 46.65 | 45.13 |
| | 134.00 | 38.26 | 45.49 | 47.39 | 47.28 | 46.36 | 45.12 |
| | 136.00 | 35.36 | 43.40 | 46.26 | 46.78 | 46.26 | 45.28 |
| | 138.00 | 31.37 | 39.96 | 43.78 | 45.01 | 44.58 | 44.34 |
| | 140.00 | 30.09 | 38.75 | 43.15 | 44.87 | 45.18 | 44.77 |

Table E- 5 --continued

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 160.00 | 110.00 | 93.24 | 74.06 | 60.36 | 51.35 | 45.08 | 40.48 |
| | 112.00 | 92.00 | 74.30 | 62.33 | 54.37 | 48.71 | 44.44 |
| | 114.00 | 90.20 | 73.74 | 63.22 | 56.18 | 51.08 | 47.16 |
| | 116.00 | 86.01 | 73.08 | 63.92 | 57.72 | 53.13 | 49.53 |
| | 118.00 | 85.15 | 72.02 | 64.16 | 58.74 | 54.63 | 51.34 |
| | 120.00 | 81.17 | 70.19 | 63.59 | 58.91 | 55.28 | 52.30 |
| | 122.00 | 76.13 | 67.93 | 62.63 | 58.69 | 55.52 | 52.85 |
| | 124.00 | 70.79 | 65.95 | 61.99 | 58.77 | 56.03 | 53.63 |
| | 126.00 | 64.46 | 65.32 | 60.75 | 58.26 | 55.97 | 53.87 |
| | 128.00 | 58.50 | 60.95 | 59.76 | 57.99 | 56.12 | 54.30 |
| | 130.00 | 53.45 | 58.93 | 59.07 | 57.97 | 56.50 | 54.94 |
| | 132.00 | 47.85 | 55.94 | 57.45 | 57.09 | 56.07 | 54.88 |
| | 134.00 | 43.32 | 53.23 | 56.82 | 56.36 | 55.76 | 54.76 |
| | 136.00 | 39.87 | 50.89 | 54.80 | 55.90 | 55.61 | 54.87 |
| | 138.00 | 35.44 | 47.22 | 52.30 | 54.07 | 54.37 | 53.96 |
| | 140.00 | 33.76 | 45.65 | 51.49 | 53.83 | 54.48 | 54.31 |
| 200.00 | 110.00 | 94.55 | 78.62 | 66.74 | 58.64 | 52.84 | 48.48 |
| | 112.00 | 93.54 | 78.81 | 66.46 | 61.37 | 56.21 | 52.24 |
| | 114.00 | 92.06 | 78.32 | 69.22 | 62.99 | 58.38 | 54.77 |
| | 116.00 | 90.25 | 77.72 | 69.82 | 64.36 | 60.24 | 56.96 |
| | 118.00 | 87.85 | 76.79 | 70.00 | 65.24 | 61.58 | 58.61 |
| | 120.00 | 84.46 | 75.17 | 69.47 | 65.38 | 62.15 | 59.47 |
| | 122.00 | 80.06 | 73.25 | 68.59 | 65.16 | 62.36 | 59.97 |
| | 124.00 | 75.24 | 71.34 | 67.98 | 65.20 | 62.79 | 60.66 |
| | 126.00 | 69.31 | 66.92 | 66.83 | 64.72 | 62.72 | 60.87 |
| | 128.00 | 63.45 | 66.67 | 65.89 | 64.44 | 62.84 | 61.24 |
| | 130.00 | 58.21 | 64.70 | 65.20 | 64.38 | 63.15 | 61.88 |
| | 132.00 | 52.35 | 61.79 | 63.67 | 63.55 | 62.74 | 61.66 |
| | 134.00 | 47.43 | 59.07 | 62.27 | 62.84 | 62.43 | 61.60 |
| | 136.00 | 43.55 | 56.63 | 61.06 | 62.28 | 62.26 | 61.68 |
| | 138.00 | 38.76 | 52.90 | 58.64 | 60.65 | 61.18 | 60.84 |
| | 140.00 | 36.74 | 51.10 | 57.76 | 60.36 | 61.17 | 61.13 |
| 240.00 | 110.00 | 95.43 | 81.82 | 71.37 | 64.87 | 58.75 | 54.68 |
| | 112.00 | 94.58 | 81.98 | 72.89 | 66.55 | 61.85 | 58.19 |
| | 114.00 | 93.33 | 81.54 | 73.56 | 68.00 | 63.83 | 60.53 |
| | 116.00 | 91.78 | 81.01 | 74.08 | 69.22 | 65.51 | 62.53 |
| | 118.00 | 89.72 | 80.17 | 74.22 | 70.90 | 66.72 | 64.03 |
| | 120.00 | 86.77 | 78.73 | 73.74 | 70.11 | 67.23 | 64.81 |
| | 122.00 | 82.89 | 76.91 | 72.93 | 69.90 | 67.40 | 65.25 |
| | 124.00 | 78.52 | 75.27 | 72.36 | 69.92 | 67.78 | 65.88 |
| | 126.00 | 73.00 | 73.05 | 71.31 | 69.47 | 67.71 | 66.06 |
| | 128.00 | 67.33 | 70.95 | 70.42 | 69.20 | 67.80 | 66.39 |
| | 130.00 | 62.06 | 69.07 | 69.75 | 69.12 | 68.07 | 66.89 |
| | 132.00 | 56.05 | 66.28 | 66.32 | 66.34 | 67.66 | 66.74 |
| | 134.00 | 50.87 | 63.63 | 67.00 | 67.67 | 67.38 | 66.68 |
| | 136.00 | 46.67 | 61.19 | 65.82 | 67.13 | 67.21 | 66.74 |
| | 138.00 | 41.58 | 57.48 | 63.52 | 65.61 | 66.14 | 65.97 |
| | 140.00 | 39.27 | 55.55 | 62.61 | 65.30 | 66.17 | 66.22 |

Table E.6 Simulated quality retention of foods with thermal diffusivity 1.6 x $10^{-7}$ $m^2/s$ after thermal processing in the conically shaped container #1 using Infinite h

| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| | | % Retention | | | | | |
| 40.00 | 110.00 | 76.61 | 32.63 | 15.39 | 8.49 | 5.26 | 3.53 |
| | 112.00 | 73.40 | 33.95 | 18.04 | 10.99 | 7.36 | 5.26 |
| | 114.00 | 69.08 | 34.11 | 19.77 | 12.94 | 9.16 | 6.84 |
| | 116.00 | 63.72 | 33.43 | 20.78 | 14.33 | 10.60 | 8.19 |
| | 118.00 | 57.39 | 32.08 | 21.14 | 15.25 | 11.64 | 9.23 |
| | 120.00 | 50.92 | 30.67 | 21.32 | 15.99 | 12.56 | 10.18 |
| | 122.00 | 44.41 | 28.96 | 21.13 | 16.39 | 13.19 | 10.90 |
| | 124.00 | 39.61 | 28.11 | 21.49 | 17.19 | 14.15 | 11.90 |
| | 126.00 | 32.96 | 25.09 | 19.96 | 16.38 | 13.74 | 11.72 |
| | 128.00 | 29.77 | 24.23 | 20.01 | 16.83 | 14.38 | 12.43 |
| | 130.00 | 26.01 | 22.38 | 19.12 | 16.46 | 14.30 | 12.52 |
| | 132.00 | 23.40 | 21.07 | 18.54 | 16.30 | 14.37 | 12.74 |
| | 134.00 | 21.73 | 20.36 | 18.28 | 16.35 | 14.61 | 13.09 |
| | 136.00 | 20.84 | 19.93 | 18.32 | 16.64 | 15.04 | 13.59 |
| | 138.00 | 18.29 | 18.11 | 17.03 | 15.72 | 14.39 | 13.14 |
| | 140.00 | 16.21 | 16.60 | 15.94 | 14.95 | 13.86 | 12.78 |
| 80.00 | 110.00 | 87.47 | 56.80 | 38.87 | 28.83 | 22.69 | 18.62 |
| | 112.00 | 85.54 | 57.77 | 41.94 | 32.71 | 26.79 | 22.69 |
| | 114.00 | 82.83 | 57.66 | 43.74 | 35.38 | 29.82 | 25.83 |
| | 116.00 | 79.22 | 56.75 | 44.62 | 37.14 | 31.99 | 28.20 |
| | 118.00 | 74.57 | 55.15 | 44.74 | 38.12 | 33.42 | 30.86 |
| | 120.00 | 69.19 | 53.36 | 44.63 | 38.85 | 34.00 | 31.29 |
| | 122.00 | 62.99 | 51.14 | 44.05 | 39.11 | 35.33 | 32.29 |
| | 124.00 | 57.40 | 49.58 | 44.03 | 39.82 | 36.45 | 33.65 |
| | 126.00 | 49.63 | 45.80 | 41.90 | 38.58 | 35.73 | 33.27 |
| | 128.00 | 44.70 | 43.99 | 41.44 | 38.82 | 36.38 | 34.16 |
| | 130.00 | 39.26 | 41.11 | 39.91 | 38.05 | 36.87 | 34.15 |
| | 132.00 | 35.13 | 38.72 | 38.68 | 37.50 | 35.94 | 34.30 |
| | 134.00 | 32.19 | 36.87 | 37.77 | 37.19 | 36.02 | 34.63 |
| | 136.00 | 30.28 | 35.56 | 37.21 | 37.15 | 36.32 | 35.15 |
| | 138.00 | 26.92 | 32.69 | 35.10 | 35.64 | 35.23 | 34.36 |
| | 140.00 | 24.17 | 30.21 | 33.19 | 34.26 | 34.25 | 33.68 |
| 120.00 | 110.00 | 91.45 | 68.50 | 53.14 | 43.54 | 37.12 | 32.54 |
| | 112.00 | 90.09 | 69.22 | 55.86 | 47.33 | 41.44 | 37.10 |
| | 114.00 | 88.13 | 69.07 | 57.40 | 49.83 | 44.48 | 40.44 |
| | 116.00 | 85.47 | 68.24 | 58.10 | 51.42 | 46.58 | 42.85 |
| | 118.00 | 81.92 | 66.81 | 58.11 | 52.27 | 47.93 | 44.50 |
| | 120.00 | 77.61 | 65.37 | 57.91 | 52.87 | 49.01 | 45.88 |
| | 122.00 | 72.32 | 63.11 | 57.28 | 53.03 | 49.64 | 46.82 |
| | 124.00 | 67.11 | 61.52 | 57.11 | 53.59 | 50.64 | 48.09 |
| | 126.00 | 59.57 | 57.92 | 55.06 | 52.36 | 49.91 | 47.69 |
| | 128.00 | 54.07 | 55.92 | 54.45 | 52.47 | 50.44 | 48.50 |
| | 130.00 | 47.92 | 52.86 | 52.84 | 51.63 | 50.08 | 48.44 |
| | 132.00 | 42.90 | 50.14 | 51.46 | 50.99 | 49.87 | 48.53 |
| | 134.00 | 39.11 | 47.85 | 50.34 | 50.55 | 49.85 | 48.78 |
| | 136.00 | 36.45 | 46.03 | 49.52 | 50.34 | 50.03 | 49.21 |
| | 138.00 | 32.49 | 42.67 | 47.19 | 48.74 | 48.90 | 48.39 |
| | 140.00 | 29.26 | 39.66 | 45.02 | 47.24 | 47.86 | 47.67 |

Table E- 6 --continued

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 160.00 | 110.00 | 93.51 | 75.26 | 62.19 | 53.55 | 47.51 | 43.05 |
| | 112.00 | 92.45 | 75.83 | 64.54 | 57.00 | 51.59 | 47.50 |
| | 114.00 | 90.93 | 75.67 | 65.85 | 59.22 | 54.39 | 50.65 |
| | 116.00 | 88.83 | 74.95 | 66.42 | 60.61 | 56.30 | 52.90 |
| | 118.00 | 85.98 | 73.71 | 66.39 | 61.34 | 57.58 | 54.60 |
| | 120.00 | 82.42 | 72.27 | 66.17 | 61.83 | 58.45 | 55.65 |
| | 122.00 | 77.92 | 70.43 | 65.57 | 61.94 | 58.99 | 56.49 |
| | 124.00 | 73.23 | 68.95 | 65.35 | 62.39 | 59.65 | 57.62 |
| | 126.00 | 66.22 | 65.70 | 63.49 | 61.26 | 59.17 | 57.24 |
| | 128.00 | 60.66 | 63.75 | 62.86 | 61.31 | 59.62 | 57.94 |
| | 130.00 | 54.25 | 60.79 | 61.33 | 60.51 | 59.25 | 57.87 |
| | 132.00 | 48.74 | 58.38 | 59.98 | 59.88 | 59.03 | 57.92 |
| | 134.00 | 44.56 | 55.63 | 58.83 | 59.40 | 58.97 | 58.12 |
| | 136.00 | 41.13 | 53.58 | 57.93 | 59.13 | 59.08 | 58.47 |
| | 138.00 | 36.71 | 50.04 | 55.63 | 57.60 | 58.01 | 57.71 |
| | 140.00 | 33.08 | 46.77 | 53.42 | 56.13 | 57.01 | 57.02 |
| 200.00 | 110.00 | 94.77 | 79.64 | 68.36 | 60.65 | 55.11 | 50.94 |
| | 112.00 | 93.91 | 80.12 | 70.41 | 63.74 | 58.80 | 55.18 |
| | 114.00 | 92.66 | 79.97 | 71.53 | 65.72 | 61.40 | 58.00 |
| | 116.00 | 90.93 | 79.34 | 72.01 | 66.94 | 63.11 | 60.04 |
| | 118.00 | 88.55 | 78.25 | 71.97 | 67.56 | 64.17 | 61.40 |
| | 120.00 | 85.54 | 76.88 | 71.75 | 67.98 | 65.00 | 62.52 |
| | 122.00 | 81.64 | 75.35 | 71.20 | 68.06 | 65.48 | 63.27 |
| | 124.00 | 77.44 | 74.00 | 70.97 | 68.44 | 66.23 | 64.27 |
| | 126.00 | 71.90 | 71.88 | 69.38 | 67.41 | 65.61 | 63.92 |
| | 128.00 | 65.58 | 69.24 | 68.69 | 67.42 | 65.99 | 64.53 |
| | 130.00 | 59.14 | 66.47 | 67.28 | 66.68 | 65.64 | 64.45 |
| | 132.00 | 53.38 | 63.84 | 66.00 | 66.07 | 65.42 | 64.49 |
| | 134.00 | 48.60 | 61.42 | 64.89 | 65.62 | 65.34 | 64.65 |
| | 136.00 | 44.94 | 59.30 | 63.98 | 65.33 | 65.42 | 64.95 |
| | 138.00 | 40.15 | 55.74 | 61.60 | 63.90 | 64.43 | 64.25 |
| | 140.00 | 36.19 | 52.35 | 59.66 | 62.52 | 63.58 | 63.61 |
| 240.00 | 110.00 | 95.62 | 82.71 | 72.82 | 65.90 | 60.85 | 56.98 |
| | 112.00 | 94.89 | 83.12 | 74.63 | 68.69 | 64.28 | 60.94 |
| | 114.00 | 93.84 | 82.98 | 75.61 | 70.45 | 66.57 | 63.58 |
| | 116.00 | 92.36 | 82.42 | 76.02 | 71.53 | 68.11 | 65.35 |
| | 118.00 | 90.33 | 81.46 | 75.97 | 72.08 | 69.06 | 66.57 |
| | 120.00 | 87.72 | 80.33 | 75.76 | 72.45 | 69.80 | 67.58 |
| | 122.00 | 84.28 | 78.87 | 75.26 | 72.50 | 70.22 | 68.25 |
| | 124.00 | 80.50 | 77.65 | 75.04 | 72.82 | 70.88 | 69.14 |
| | 126.00 | 74.60 | 75.81 | 73.52 | 71.90 | 70.32 | 68.82 |
| | 128.00 | 69.40 | 73.31 | 72.96 | 71.89 | 70.64 | 69.36 |
| | 130.00 | 63.06 | 70.73 | 71.66 | 71.21 | 70.32 | 69.28 |
| | 132.00 | 57.18 | 68.23 | 70.47 | 70.64 | 70.11 | 69.31 |
| | 134.00 | 52.15 | 65.89 | 69.42 | 70.21 | 70.03 | 69.44 |
| | 136.00 | 48.15 | 63.77 | 68.54 | 69.92 | 70.08 | 69.70 |
| | 138.00 | 43.06 | 60.27 | 66.48 | 68.60 | 69.17 | 69.80 |
| | 140.00 | 38.82 | 56.87 | 64.64 | 67.31 | 68.32 | 68.47 |

Table E- 7 Simulated quality retention of foods with thermal diffusivity $1.2 \times 10^{-7}$ $m^2/s$ after thermal processing in the conically shaped container #2, h = 300 w/$m^2$K

**% Retention**

| **D (mm)** | **Temp(°C)** | **Z = 10°C** | **Z = 20°C** | **Z = 30°C** | **Z = 40°C** | **Z = 50°C** | **Z = 60°C** |
|---|---|---|---|---|---|---|---|
| 40.00 | 110.00 | 77.74 | 34.68 | 17.07 | 9.78 | 6.26 | 4.34 |
| | 112.00 | 74.57 | 35.81 | 19.69 | 12.37 | 8.53 | 6.26 |
| | 114.00 | 70.79 | 36.36 | 21.81 | 14.71 | 10.71 | 8.22 |
| | 116.00 | 66.08 | 36.09 | 23.20 | 16.51 | 12.53 | 9.93 |
| | 118.00 | 60.43 | 35.12 | 23.92 | 17.78 | 13.94 | 11.33 |
| | 120.00 | 54.56 | 34.18 | 24.48 | 18.88 | 15.21 | 12.62 |
| | 122.00 | 46.51 | 31.28 | 23.42 | 18.62 | 15.33 | 12.95 |
| | 124.00 | 41.72 | 30.63 | 24.10 | 19.75 | 16.62 | 14.27 |
| | 126.00 | 36.70 | 29.38 | 24.04 | 20.23 | 17.35 | 15.11 |
| | 128.00 | 31.00 | 26.83 | 22.92 | 19.78 | 17.27 | 15.23 |
| | 130.00 | 26.82 | 24.95 | 22.14 | 19.56 | 17.36 | 15.58 |
| | 132.00 | 23.99 | 23.67 | 21.71 | 19.58 | 17.62 | 15.90 |
| | 134.00 | 22.32 | 22.96 | 21.65 | 19.88 | 18.13 | 16.52 |
| | 136.00 | 18.89 | 20.53 | 20.02 | 18.80 | 17.40 | 16.04 |
| | 138.00 | 18.92 | 20.82 | 20.61 | 19.58 | 18.29 | 16.98 |
| | 140.00 | 16.79 | 19.18 | 19.46 | 18.82 | 17.81 | 16.69 |
| 80.00 | 110.00 | 88.14 | 58.78 | 41.08 | 31.06 | 24.85 | 20.70 |
| | 112.00 | 86.28 | 59.54 | 44.03 | 34.89 | 28.97 | 24.85 |
| | 114.00 | 83.97 | 59.85 | 46.24 | 37.97 | 32.42 | 28.43 |
| | 116.00 | 80.95 | 59.41 | 47.54 | 40.13 | 35.01 | 31.22 |
| | 118.00 | 77.06 | 58.33 | 48.10 | 41.53 | 36.85 | 33.30 |
| | 120.00 | 72.59 | 57.11 | 48.46 | 42.68 | 38.42 | 35.09 |
| | 122.00 | 65.90 | 54.13 | 47.12 | 42.22 | 38.48 | 35.48 |
| | 124.00 | 60.90 | 53.07 | 47.52 | 43.33 | 39.96 | 37.18 |
| | 126.00 | 55.10 | 51.22 | 47.14 | 43.67 | 40.72 | 38.18 |
| | 128.00 | 48.36 | 48.16 | 45.62 | 42.95 | 40.48 | 38.25 |
| | 130.00 | 42.33 | 45.51 | 44.39 | 42.47 | 40.44 | 38.50 |
| | 132.00 | 37.83 | 43.35 | 43.49 | 42.24 | 40.59 | 38.89 |
| | 134.00 | 34.67 | 41.75 | 42.95 | 42.38 | 41.02 | 39.54 |
| | 136.00 | 29.82 | 38.26 | 40.67 | 40.77 | 39.98 | 38.83 |
| | 138.00 | 28.87 | 37.72 | 40.81 | 41.35 | 40.83 | 39.85 |
| | 140.00 | 25.82 | 35.08 | 39.08 | 40.16 | 40.06 | 39.37 |
| 120.00 | 110.00 | 91.92 | 70.05 | 55.19 | 45.88 | 39.47 | 34.95 |
| | 112.00 | 90.61 | 70.70 | 57.78 | 49.47 | 43.71 | 39.46 |
| | 114.00 | 88.97 | 70.89 | 59.66 | 52.31 | 47.10 | 43.16 |
| | 116.00 | 86.78 | 70.49 | 60.73 | 54.25 | 49.55 | 45.92 |
| | 118.00 | 83.88 | 69.55 | 61.15 | 55.47 | 51.24 | 47.92 |
| | 120.00 | 80.42 | 68.46 | 61.39 | 56.44 | 52.66 | 49.61 |
| | 122.00 | 75.05 | 65.90 | 60.17 | 55.99 | 52.68 | 49.95 |
| | 124.00 | 70.67 | 64.86 | 60.42 | 56.91 | 54.00 | 51.52 |
| | 126.00 | 65.26 | 63.10 | 59.97 | 57.14 | 54.64 | 52.41 |
| | 128.00 | 58.43 | 60.22 | 58.53 | 56.44 | 54.37 | 52.44 |
| | 130.00 | 52.17 | 57.59 | 57.31 | 55.93 | 54.29 | 52.63 |
| | 132.00 | 46.93 | 55.30 | 56.35 | 55.63 | 54.38 | 52.96 |
| | 134.00 | 42.94 | 53.44 | 55.68 | 55.59 | 54.69 | 53.51 |
| | 136.00 | 37.28 | 49.75 | 53.42 | 54.10 | 53.69 | 52.82 |
| | 138.00 | 35.58 | 48.76 | 53.31 | 54.51 | 54.39 | 53.71 |
| | 140.00 | 31.85 | 45.74 | 51.40 | 53.29 | 53.61 | 53.22 |

Table E-7--continued

| D (min) | Temp(°C) | % Retention<br>Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 50°C |
|---|---|---|---|---|---|---|---|
| 160.00 | 110.00 | 93.88 | 76.55 | 64.00 | 55.64 | 49.77 | 45.43 |
| | 112.00 | 92.87 | 77.07 | 66.23 | 58.94 | 53.72 | 49.76 |
| | 114.00 | 91.59 | 77.21 | 67.82 | 61.46 | 56.80 | 53.21 |
| | 116.00 | 89.88 | 76.85 | 68.71 | 63.14 | 59.00 | 55.74 |
| | 118.00 | 87.58 | 76.05 | 69.05 | 64.19 | 60.50 | 57.54 |
| | 120.00 | 84.78 | 75.11 | 69.22 | 65.01 | 61.74 | 59.05 |
| | 122.00 | 80.35 | 72.92 | 68.25 | 64.60 | 61.74 | 59.34 |
| | 124.00 | 76.55 | 71.97 | 68.32 | 65.37 | 62.88 | 60.72 |
| | 126.00 | 71.70 | 70.38 | 67.89 | 65.54 | 63.42 | 61.50 |
| | 128.00 | 65.31 | 67.81 | 66.59 | 64.90 | 63.17 | 61.51 |
| | 130.00 | 59.09 | 65.38 | 65.47 | 64.42 | 63.07 | 61.67 |
| | 132.00 | 53.56 | 63.18 | 64.55 | 64.11 | 63.12 | 61.94 |
| | 134.00 | 49.09 | 61.30 | 63.86 | 64.03 | 63.37 | 62.41 |
| | 136.00 | 42.96 | 57.71 | 61.78 | 62.68 | 62.46 | 61.78 |
| | 138.00 | 40.72 | 56.52 | 61.57 | 62.97 | 63.34 | 62.54 |
| | 140.00 | 36.50 | 53.40 | 59.73 | 61.84 | 62.32 | 62.09 |
| 200.00 | 110.00 | 95.07 | 80.74 | 69.96 | 62.55 | 57.21 | 53.10 |
| | 112.00 | 94.25 | 81.17 | 71.89 | 65.49 | 60.81 | 57.20 |
| | 114.00 | 93.21 | 81.28 | 73.27 | 67.71 | 63.58 | 60.35 |
| | 116.00 | 91.80 | 80.97 | 74.03 | 69.19 | 65.53 | 62.62 |
| | 118.00 | 89.90 | 80.27 | 74.30 | 70.09 | 66.86 | 64.24 |
| | 120.00 | 87.56 | 79.45 | 74.43 | 70.81 | 67.94 | 65.57 |
| | 122.00 | 83.80 | 77.56 | 73.49 | 70.43 | 67.94 | 65.83 |
| | 124.00 | 80.48 | 76.70 | 73.62 | 71.09 | 68.93 | 67.05 |
| | 126.00 | 76.13 | 75.39 | 73.22 | 71.22 | 69.39 | 67.73 |
| | 128.00 | 70.24 | 72.98 | 72.06 | 70.64 | 69.16 | 67.73 |
| | 130.00 | 64.24 | 70.77 | 71.04 | 70.20 | 69.06 | 67.86 |
| | 132.00 | 58.66 | 68.72 | 70.20 | 69.91 | 69.10 | 68.09 |
| | 134.00 | 53.92 | 66.91 | 69.55 | 69.81 | 69.30 | 68.49 |
| | 136.00 | 47.53 | 63.53 | 67.64 | 68.60 | 68.48 | 67.93 |
| | 138.00 | 44.86 | 62.25 | 67.38 | 68.82 | 68.97 | 68.59 |
| | 140.00 | 40.30 | 59.18 | 65.66 | 67.79 | 68.32 | 68.18 |
| 240.00 | 110.00 | 95.87 | 83.67 | 74.24 | 67.62 | 62.78 | 59.08 |
| | 112.00 | 95.18 | 84.03 | 75.95 | 70.27 | 66.05 | 62.77 |
| | 114.00 | 94.39 | 84.12 | 77.15 | 72.24 | 68.55 | 65.63 |
| | 116.00 | 93.11 | 83.85 | 77.81 | 73.55 | 70.30 | 67.69 |
| | 118.00 | 91.49 | 83.23 | 78.04 | 74.34 | 71.48 | 69.14 |
| | 120.00 | 89.48 | 82.51 | 78.15 | 74.97 | 72.44 | 70.33 |
| | 122.00 | 86.22 | 80.85 | 77.31 | 74.63 | 72.43 | 70.56 |
| | 124.00 | 83.28 | 80.08 | 77.41 | 75.20 | 73.31 | 71.64 |
| | 126.00 | 79.36 | 78.80 | 77.04 | 75.31 | 73.71 | 72.24 |
| | 128.00 | 73.95 | 76.74 | 76.00 | 74.79 | 73.50 | 72.24 |
| | 130.00 | 68.24 | 74.72 | 75.08 | 74.38 | 73.40 | 72.35 |
| | 132.00 | 62.72 | 72.83 | 74.30 | 74.12 | 73.42 | 72.55 |
| | 134.00 | 57.86 | 71.12 | 73.70 | 74.01 | 73.60 | 72.98 |
| | 136.00 | 51.32 | 67.95 | 71.96 | 72.91 | 72.86 | 72.39 |
| | 138.00 | 48.36 | 66.66 | 71.68 | 73.09 | 73.28 | 72.97 |
| | 140.00 | 43.51 | 63.69 | 70.09 | 72.15 | 72.69 | 72.60 |

Table E- 8 Simulated quality retention of foods with thermal diffusivity $1.4 \times 10^{-7}$ $m^2/s$ after thermal processing in the conically shaped container #2, h = 300 $w/m^2K$

% Retention

| D (mm) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| 40.00 | 110.00 | 78.53 | 36.56 | 18.82 | 11.21 | 7.42 | 5.30 |
| | 112.00 | 75.84 | 38.34 | 22.18 | 14.46 | 10.31 | 7.80 |
| | 114.00 | 72.85 | 38.71 | 24.19 | 16.90 | 12.68 | 10.00 |
| | 116.00 | 68.85 | 39.08 | 26.19 | 19.30 | 15.08 | 12.25 |
| | 118.00 | 61.94 | 37.47 | 26.43 | 20.24 | 16.28 | 13.53 |
| | 120.00 | 56.77 | 37.01 | 27.52 | 21.86 | 18.05 | 15.32 |
| | 122.00 | 49.24 | 34.49 | 26.78 | 21.90 | 18.48 | 15.94 |
| | 124.00 | 42.85 | 32.72 | 26.54 | 22.32 | 19.21 | 16.83 |
| | 126.00 | 38.21 | 31.80 | 26.89 | 23.19 | 20.30 | 18.00 |
| | 128.00 | 32.68 | 29.59 | 26.03 | 22.99 | 20.46 | 18.36 |
| | 130.00 | 28.74 | 28.01 | 25.56 | 23.08 | 20.86 | 18.93 |
| | 132.00 | 26.27 | 27.11 | 25.52 | 23.49 | 21.51 | 19.71 |
| | 134.00 | 21.93 | 24.25 | 23.71 | 22.33 | 20.76 | 19.25 |
| | 136.00 | 21.71 | 28.53 | 24.42 | 23.31 | 21.88 | 20.43 |
| | 138.00 | 19.14 | 22.60 | 23.16 | 22.52 | 21.43 | 20.20 |
| | 140.00 | 17.22 | 21.07 | 22.14 | 21.90 | 21.09 | 20.06 |
| 80.00 | 110.00 | 88.80 | 60.32 | 43.28 | 33.31 | 27.11 | 22.91 |
| | 112.00 | 87.18 | 61.69 | 46.74 | 37.79 | 31.92 | 27.79 |
| | 114.00 | 84.76 | 61.86 | 48.81 | 40.80 | 35.37 | 31.42 |
| | 116.00 | 82.23 | 62.00 | 50.68 | 43.52 | 38.51 | 34.76 |
| | 118.00 | 78.17 | 60.47 | 50.76 | 44.48 | 39.95 | 36.49 |
| | 120.00 | 74.33 | 59.83 | 51.63 | 46.11 | 42.01 | 38.78 |
| | 122.00 | 68.30 | 57.32 | 50.71 | 46.03 | 42.42 | 39.50 |
| | 124.00 | 62.33 | 55.33 | 50.24 | 46.33 | 43.17 | 40.53 |
| | 126.00 | 57.06 | 53.98 | 50.29 | 47.07 | 44.28 | 41.85 |
| | 128.00 | 50.46 | 51.32 | 49.13 | 46.68 | 44.34 | 42.21 |
| | 130.00 | 44.98 | 49.12 | 48.32 | 46.57 | 44.65 | 42.77 |
| | 132.00 | 40.89 | 47.47 | 47.89 | 46.77 | 45.22 | 43.57 |
| | 134.00 | 34.92 | 43.78 | 45.63 | 45.32 | 44.26 | 42.95 |
| | 136.00 | 33.43 | 43.22 | 45.92 | 46.09 | 45.31 | 44.17 |
| | 138.00 | 29.62 | 40.35 | 44.13 | 44.99 | 44.65 | 43.80 |
| | 140.00 | 26.68 | 37.88 | 42.55 | 44.04 | 44.11 | 43.53 |
| 120.00 | 110.00 | 92.24 | 71.35 | 57.09 | 48.00 | 41.84 | 37.40 |
| | 112.00 | 91.14 | 72.40 | 60.15 | 52.20 | 46.65 | 42.54 |
| | 114.00 | 89.53 | 72.51 | 61.89 | 54.91 | 49.93 | 46.16 |
| | 116.00 | 87.71 | 72.57 | 63.42 | 57.31 | 52.83 | 49.36 |
| | 118.00 | 84.72 | 71.31 | 63.45 | 58.11 | 54.12 | 50.97 |
| | 120.00 | 81.78 | 70.70 | 64.12 | 59.50 | 55.95 | 53.07 |
| | 122.00 | 77.03 | 68.80 | 63.28 | 59.38 | 56.28 | 53.70 |
| | 124.00 | 72.01 | 66.84 | 62.81 | 59.68 | 56.91 | 54.61 |
| | 126.00 | 67.18 | 65.55 | 62.76 | 60.10 | 57.86 | 55.78 |
| | 128.00 | 60.82 | 63.11 | 61.68 | 59.78 | 57.87 | 56.07 |
| | 130.00 | 55.92 | 60.97 | 60.87 | 59.62 | 58.10 | 56.54 |
| | 132.00 | 50.26 | 59.23 | 60.36 | 59.73 | 58.55 | 57.22 |
| | 134.00 | 43.60 | 55.60 | 58.24 | 58.38 | 57.66 | 56.63 |
| | 136.00 | 41.28 | 54.68 | 58.32 | 58.96 | 58.53 | 57.68 |
| | 138.00 | 36.72 | 51.61 | 56.55 | 57.90 | 57.89 | 57.32 |
| | 140.00 | 33.08 | 48.83 | 54.92 | 56.95 | 57.35 | 57.04 |

Table E-8—continued

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| D (mm) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 160.00 | 110.00 | 94.12 | 77.62 | 65.65 | 57.65 | 52.00 | 47.81 |
| | 112.00 | 93.28 | 78.46 | 68.27 | 61.38 | 56.42 | 52.65 |
| | 114.00 | 92.03 | 78.54 | 69.73 | 63.75 | 59.36 | 55.97 |
| | 116.00 | 90.61 | 78.57 | 71.01 | 65.81 | 61.92 | 58.85 |
| | 118.00 | 88.26 | 77.51 | 71.81 | 66.49 | 63.85 | 60.28 |
| | 120.00 | 85.89 | 76.98 | 71.55 | 67.66 | 64.62 | 62.12 |
| | 122.00 | 82.00 | 75.20 | 70.82 | 67.55 | 64.90 | 62.68 |
| | 124.00 | 77.73 | 73.68 | 70.39 | 67.71 | 65.44 | 63.46 |
| | 126.00 | 73.46 | 72.52 | 70.31 | 66.18 | 66.23 | 64.46 |
| | 128.00 | 67.60 | 70.37 | 69.35 | 67.82 | 66.23 | 64.70 |
| | 130.00 | 61.93 | 68.41 | 68.60 | 67.65 | 66.41 | 65.10 |
| | 132.00 | 56.95 | 66.75 | 68.10 | 67.70 | 66.78 | 65.68 |
| | 134.00 | 50.03 | 63.38 | 66.20 | 66.51 | 65.99 | 65.36 |
| | 136.00 | 47.16 | 62.35 | 66.18 | 66.97 | 66.71 | 66.04 |
| | 138.00 | 42.12 | 59.34 | 64.55 | 66.01 | 66.14 | 65.71 |
| | 140.00 | 37.99 | 56.52 | 63.00 | 65.13 | 65.64 | 65.46 |
| 200.00 | 110.00 | 95.27 | 81.64 | 71.41 | 64.35 | 59.26 | 55.40 |
| | 112.00 | 94.58 | 82.35 | 73.67 | 67.66 | 63.24 | 59.84 |
| | 114.00 | 93.57 | 82.41 | 74.92 | 69.73 | 65.87 | 62.84 |
| | 116.00 | 92.40 | 82.42 | 76.01 | 71.53 | 68.13 | 65.41 |
| | 118.00 | 90.46 | 81.52 | 76.00 | 72.11 | 69.11 | 66.68 |
| | 120.00 | 88.49 | 81.05 | 76.45 | 73.12 | 70.49 | 68.30 |
| | 122.00 | 85.21 | 79.53 | 75.81 | 73.01 | 70.72 | 68.78 |
| | 124.00 | 81.54 | 78.20 | 75.42 | 73.14 | 71.18 | 69.46 |
| | 126.00 | 77.73 | 77.17 | 75.33 | 73.53 | 71.87 | 70.34 |
| | 128.00 | 72.39 | 75.25 | 74.48 | 73.21 | 71.86 | 70.54 |
| | 130.00 | 66.99 | 73.49 | 73.80 | 73.04 | 72.00 | 70.89 |
| | 132.00 | 62.02 | 71.95 | 73.34 | 73.07 | 72.31 | 71.38 |
| | 134.00 | 55.04 | 66.87 | 71.64 | 72.01 | 71.61 | 70.92 |
| | 136.00 | 51.81 | 67.82 | 71.58 | 72.39 | 72.23 | 71.68 |
| | 138.00 | 46.47 | 64.96 | 70.09 | 71.53 | 71.71 | 71.39 |
| | 140.00 | 41.99 | 62.21 | 68.66 | 70.73 | 71.26 | 71.15 |
| 240.00 | 110.00 | 96.04 | 84.45 | 75.52 | 69.25 | 64.65 | 61.13 |
| | 112.00 | 95.46 | 85.05 | 77.51 | 72.20 | 68.25 | 65.18 |
| | 114.00 | 94.61 | 85.70 | 78.60 | 74.04 | 70.68 | 67.89 |
| | 116.00 | 93.62 | 85.10 | 79.55 | 75.62 | 72.61 | 70.20 |
| | 118.00 | 91.97 | 84.32 | 79.53 | 76.13 | 73.48 | 71.32 |
| | 120.00 | 90.28 | 83.80 | 79.92 | 77.01 | 74.70 | 72.77 |
| | 122.00 | 87.45 | 82.57 | 79.35 | 76.91 | 74.90 | 73.19 |
| | 124.00 | 84.23 | 81.40 | 79.00 | 77.12 | 75.38 | 73.79 |
| | 126.00 | 80.82 | 80.47 | 78.91 | 77.36 | 75.50 | 74.56 |
| | 128.00 | 75.95 | 78.77 | 78.15 | 77.06 | 75.89 | 74.74 |
| | 130.00 | 70.86 | 77.47 | 77.53 | 76.91 | 76.01 | 75.04 |
| | 132.00 | 66.00 | 75.76 | 77.10 | 76.92 | 76.28 | 75.47 |
| | 134.00 | 59.09 | 72.94 | 75.59 | 75.98 | 75.65 | 75.06 |
| | 136.00 | 55.62 | 71.91 | 75.50 | 76.29 | 76.19 | 75.73 |
| | 138.00 | 50.08 | 69.23 | 74.14 | 75.52 | 75.73 | 75.46 |
| | 140.00 | 45.35 | 66.59 | 72.83 | 74.79 | 75.32 | 75.25 |

Table E- 9 Simulated quality retention of foods with thermal diffusivity 1.6x $10^{-7}$ $m^2/s$ after thermal processing in the conically shaped container #2, h = 300 $w/m^2K$

|  |  | % Retention |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 40.00 | 110.00 | 79.06 | 37.93 | 20.15 | 12.34 | 8.37 | 6.11 |
|  | 112.00 | 76.64 | 40.10 | 23.89 | 16.08 | 11.74 | 9.07 |
|  | 114.00 | 73.26 | 40.92 | 26.45 | 19.00 | 14.59 | 11.73 |
|  | 116.00 | 68.81 | 40.64 | 27.96 | 21.08 | 16.81 | 13.91 |
|  | 118.00 | 64.48 | 40.76 | 29.70 | 23.34 | 19.17 | 16.23 |
|  | 120.00 | 58.40 | 39.31 | 29.99 | 24.34 | 20.47 | 17.65 |
|  | 122.00 | 51.30 | 37.10 | 29.54 | 24.65 | 21.16 | 18.53 |
|  | 124.00 | 45.37 | 35.73 | 29.67 | 25.43 | 22.24 | 19.75 |
|  | 126.00 | 41.26 | 35.33 | 30.49 | 26.76 | 23.79 | 21.38 |
|  | 128.00 | 36.02 | 33.46 | 29.97 | 26.88 | 24.26 | 22.05 |
|  | 130.00 | 29.05 | 29.62 | 27.67 | 25.42 | 23.31 | 21.44 |
|  | 132.00 | 26.85 | 29.00 | 27.91 | 26.11 | 24.22 | 22.45 |
|  | 134.00 | 22.50 | 26.17 | 26.18 | 25.04 | 23.57 | 22.08 |
|  | 136.00 | 22.74 | 26.87 | 27.31 | 26.42 | 25.08 | 23.63 |
|  | 138.00 | 20.29 | 25.04 | 26.18 | 25.79 | 24.78 | 23.56 |
|  | 140.00 | 18.54 | 23.64 | 25.32 | 25.34 | 24.62 | 23.60 |
| 80.00 | 110.00 | 88.00 | 61.47 | 44.75 | 35.00 | 28.83 | 24.62 |
|  | 112.00 | 87.50 | 63.14 | 48.66 | 39.00 | 34.11 | 30.00 |
|  | 114.00 | 85.50 | 63.69 | 51.12 | 43.33 | 37.59 | 34.09 |
|  | 116.00 | 82.74 | 63.33 | 52.48 | 45.58 | 40.71 | 37.09 |
|  | 118.00 | 79.87 | 63.24 | 53.97 | 47.88 | 43.46 | 40.04 |
|  | 120.00 | 75.59 | 61.85 | 54.05 | 48.80 | 44.85 | 41.71 |
|  | 122.00 | 70.07 | 59.75 | 53.48 | 49.01 | 45.53 | 42.69 |
|  | 124.00 | 64.72 | 58.21 | 53.40 | 49.68 | 46.60 | 44.02 |
|  | 126.00 | 60.15 | 57.40 | 53.91 | 50.81 | 48.12 | 45.76 |
|  | 128.00 | 54.11 | 55.23 | 53.15 | 50.77 | 48.49 | 46.40 |
|  | 130.00 | 45.94 | 51.12 | 50.69 | 49.17 | 47.42 | 45.68 |
|  | 132.00 | 42.11 | 49.81 | 50.58 | 49.69 | 48.24 | 46.68 |
|  | 134.00 | 36.12 | 46.29 | 48.52 | 48.39 | 47.44 | 46.21 |
|  | 136.00 | 35.07 | 46.18 | 49.22 | 49.53 | 48.83 | 47.75 |
|  | 138.00 | 31.34 | 43.51 | 47.68 | 48.65 | 48.38 | 47.57 |
|  | 140.00 | 28.52 | 41.25 | 46.35 | 47.95 | 48.06 | 47.51 |
| 120.00 | 110.00 | 92.45 | 72.27 | 58.46 | 49.62 | 43.61 | 39.26 |
|  | 112.00 | 91.47 | 73.55 | 61.80 | 54.14 | 48.77 | 44.77 |
|  | 114.00 | 90.06 | 73.95 | 63.85 | 57.18 | 52.39 | 48.75 |
|  | 116.00 | 88.09 | 73.64 | 64.94 | 59.13 | 54.86 | 51.55 |
|  | 118.00 | 85.98 | 73.51 | 66.13 | 61.88 | 57.27 | 54.24 |
|  | 120.00 | 82.76 | 72.36 | 66.18 | 61.83 | 58.47 | 55.73 |
|  | 122.00 | 78.46 | 70.61 | 65.64 | 61.97 | 59.04 | 56.59 |
|  | 124.00 | 74.83 | 69.26 | 65.50 | 62.48 | 59.94 | 57.74 |
|  | 126.00 | 69.91 | 68.46 | 65.85 | 63.41 | 61.21 | 59.23 |
|  | 128.00 | 64.24 | 66.51 | 65.14 | 63.33 | 61.50 | 59.77 |
|  | 130.00 | 56.23 | 62.85 | 62.99 | 61.92 | 60.55 | 59.12 |
|  | 132.00 | 51.77 | 61.46 | 62.78 | 62.27 | 61.21 | 59.97 |
|  | 134.00 | 45.14 | 58.08 | 60.89 | 61.12 | 60.49 | 59.53 |
|  | 136.00 | 43.25 | 57.61 | 61.34 | 62.02 | 61.63 | 60.83 |
|  | 138.00 | 38.79 | 54.82 | 59.84 | 61.19 | 61.20 | 60.64 |
|  | 140.00 | 35.26 | 52.32 | 58.50 | 60.49 | 60.88 | 60.56 |

Table E- 9--continued

| D (min) | Temp(°C) | % Retention<br>Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| 160.00 | 110.00 | 94.28 | 78.37 | 66.84 | 59.11 | 53.64 | 49.58 |
| | 112.00 | 93.53 | 79.40 | 69.68 | 63.09 | 58.34 | 54.72 |
| | 114.00 | 92.44 | 79.71 | 71.39 | 65.72 | 61.55 | 58.32 |
| | 116.00 | 90.90 | 79.45 | 72.30 | 67.39 | 63.71 | 60.81 |
| | 118.00 | 89.25 | 79.32 | 73.27 | 69.04 | 65.79 | 63.17 |
| | 120.00 | 86.68 | 78.36 | 73.29 | 69.66 | 66.81 | 64.46 |
| | 122.00 | 83.19 | 76.89 | 72.82 | 69.77 | 67.29 | 65.19 |
| | 124.00 | 79.47 | 75.73 | 72.68 | 70.18 | 68.05 | 66.19 |
| | 126.00 | 75.85 | 75.00 | 72.93 | 70.94 | 69.12 | 67.46 |
| | 128.00 | 70.71 | 73.29 | 72.30 | 70.85 | 69.35 | 67.91 |
| | 130.00 | 63.22 | 70.10 | 70.45 | 69.64 | 68.53 | 67.34 |
| | 132.00 | 58.59 | 68.78 | 70.22 | 69.91 | 69.37 | 68.05 |
| | 134.00 | 51.74 | 65.69 | 68.55 | 68.90 | 68.44 | 67.67 |
| | 136.00 | 49.31 | 65.05 | 68.86 | 69.63 | 69.39 | 68.76 |
| | 138.00 | 44.40 | 62.40 | 67.50 | 68.89 | 69.00 | 68.59 |
| | 140.00 | 40.41 | 59.90 | 66.24 | 68.25 | 68.71 | 68.51 |
| 200.00 | 110.00 | 95.40 | 82.28 | 72.44 | 65.65 | 60.75 | 57.04 |
| | 112.00 | 94.79 | 83.14 | 74.89 | 69.17 | 64.97 | 61.72 |
| | 114.00 | 93.90 | 83.40 | 76.35 | 71.46 | 67.81 | 64.95 |
| | 116.00 | 92.65 | 83.16 | 77.12 | 72.90 | 69.73 | 67.16 |
| | 118.00 | 91.28 | 83.05 | 77.94 | 74.32 | 71.52 | 69.23 |
| | 120.00 | 89.15 | 82.23 | 77.95 | 74.85 | 72.40 | 70.36 |
| | 122.00 | 86.22 | 80.97 | 77.53 | 74.93 | 72.81 | 70.99 |
| | 124.00 | 83.03 | 79.96 | 77.40 | 75.28 | 73.46 | 71.85 |
| | 126.00 | 78.84 | 79.31 | 77.60 | 75.92 | 74.37 | 72.95 |
| | 128.00 | 75.21 | 77.81 | 77.04 | 75.84 | 74.57 | 73.33 |
| | 130.00 | 68.29 | 75.00 | 75.42 | 74.78 | 73.85 | 72.84 |
| | 132.00 | 63.68 | 73.78 | 75.20 | 75.00 | 74.31 | 73.45 |
| | 134.00 | 56.85 | 70.99 | 73.72 | 74.11 | 73.76 | 73.11 |
| | 136.00 | 54.06 | 70.34 | 73.95 | 74.72 | 74.57 | 74.05 |
| | 138.00 | 48.87 | 67.82 | 72.72 | 74.06 | 74.22 | 73.90 |
| | 140.00 | 44.55 | 65.41 | 71.58 | 73.48 | 73.95 | 73.82 |
| 240.00 | 110.00 | 96.15 | 84.99 | 76.43 | 70.41 | 68.81 | 62.63 |
| | 112.00 | 95.84 | 85.73 | 78.58 | 73.54 | 69.80 | 68.88 |
| | 114.00 | 94.89 | 85.95 | 78.85 | 75.57 | 72.34 | 69.78 |
| | 116.00 | 93.83 | 85.75 | 80.52 | 76.83 | 74.02 | 71.75 |
| | 118.00 | 92.67 | 85.64 | 81.23 | 78.07 | 75.61 | 73.59 |
| | 120.00 | 90.85 | 84.92 | 81.23 | 78.53 | 76.39 | 74.59 |
| | 122.00 | 88.32 | 83.83 | 80.86 | 78.60 | 76.74 | 75.15 |
| | 124.00 | 85.54 | 82.94 | 80.73 | 78.90 | 77.31 | 75.90 |
| | 126.00 | 82.70 | 82.35 | 80.90 | 79.46 | 78.11 | 76.87 |
| | 128.00 | 78.52 | 81.02 | 80.40 | 79.37 | 78.27 | 77.20 |
| | 130.00 | 72.13 | 78.53 | 78.97 | 78.44 | 77.64 | 76.77 |
| | 132.00 | 67.65 | 77.41 | 78.76 | 78.62 | 78.04 | 77.30 |
| | 134.00 | 60.95 | 74.88 | 77.44 | 77.83 | 77.55 | 77.00 |
| | 136.00 | 57.92 | 74.23 | 77.62 | 78.36 | 78.25 | 77.82 |
| | 138.00 | 52.56 | 71.89 | 76.51 | 77.77 | 77.94 | 77.68 |
| | 140.00 | 48.02 | 69.60 | 75.46 | 77.24 | 77.70 | 77.60 |

Table E- 10 Simulated quality retention of foods with thermal diffusivity $1.2 \times 10^{-7}$ $m^2/s$ after thermal processing in the conically shaped container #2 using Infinite h

| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| | | % Retention | | | | | |
| 40.00 | 110.00 | 77.56 | 35.21 | 17.85 | 10.53 | 6.92 | 4.91 |
| | 112.00 | 74.39 | 36.60 | 20.80 | 13.49 | 9.56 | 7.20 |
| | 114.00 | 69.98 | 36.59 | 22.58 | 15.85 | 11.67 | 9.15 |
| | 116.00 | 65.22 | 36.54 | 24.24 | 17.75 | 13.60 | 11.17 |
| | 118.00 | 58.39 | 34.66 | 24.25 | 18.48 | 14.81 | 12.27 |
| | 120.00 | 52.44 | 33.82 | 25.02 | 19.80 | 16.30 | 13.79 |
| | 122.00 | 46.41 | 32.68 | 25.40 | 20.77 | 17.58 | 15.07 |
| | 124.00 | 40.13 | 30.85 | 25.09 | 21.10 | 18.15 | 15.87 |
| | 126.00 | 33.36 | 27.99 | 23.75 | 20.52 | 17.98 | 15.94 |
| | 128.00 | 28.29 | 25.75 | 22.77 | 20.17 | 17.99 | 16.16 |
| | 130.00 | 24.82 | 24.15 | 22.16 | 20.08 | 18.19 | 18.52 |
| | 132.00 | 22.71 | 23.19 | 21.94 | 20.29 | 18.64 | 17.11 |
| | 134.00 | 21.74 | 22.88 | 22.14 | 20.81 | 19.34 | 17.92 |
| | 136.00 | 18.80 | 20.76 | 20.69 | 19.84 | 18.71 | 17.52 |
| | 138.00 | 16.48 | 19.06 | 19.48 | 19.03 | 18.19 | 17.20 |
| | 140.00 | 14.67 | 17.72 | 18.51 | 18.37 | 17.78 | 16.98 |
| 80.00 | 110.00 | 88.03 | 59.14 | 42.01 | 32.24 | 26.15 | 22.04 |
| | 112.00 | 86.17 | 60.18 | 45.26 | 36.43 | 30.69 | 28.66 |
| | 114.00 | 83.48 | 60.01 | 47.03 | 39.16 | 33.85 | 30.01 |
| | 116.00 | 80.37 | 59.74 | 48.58 | 41.60 | 36.75 | 33.12 |
| | 118.00 | 75.62 | 57.86 | 48.40 | 42.33 | 37.99 | 34.66 |
| | 120.00 | 71.90 | 56.74 | 48.92 | 43.68 | 39.77 | 36.68 |
| | 122.00 | 65.48 | 55.25 | 49.02 | 44.58 | 41.11 | 38.29 |
| | 124.00 | 59.01 | 53.02 | 48.38 | 44.74 | 41.75 | 39.21 |
| | 126.00 | 51.31 | 49.64 | 46.67 | 43.89 | 41.41 | 39.21 |
| | 128.00 | 44.54 | 46.64 | 45.23 | 43.27 | 41.28 | 39.39 |
| | 130.00 | 39.17 | 44.12 | 44.13 | 42.91 | 41.34 | 39.72 |
| | 132.00 | 35.33 | 42.17 | 43.39 | 42.84 | 41.68 | 40.32 |
| | 134.00 | 32.95 | 40.84 | 43.06 | 43.10 | 42.29 | 41.15 |
| | 136.00 | 28.90 | 37.62 | 40.91 | 41.68 | 41.36 | 40.54 |
| | 138.00 | 25.72 | 34.82 | 38.98 | 40.41 | 40.53 | 40.02 |
| | 140.00 | 23.23 | 32.46 | 37.27 | 39.28 | 39.81 | 39.60 |
| 120.00 | 110.00 | 91.85 | 70.40 | 56.02 | 46.95 | 40.84 | 36.45 |
| | 112.00 | 90.53 | 71.20 | 58.84 | 50.92 | 45.42 | 41.36 |
| | 114.00 | 89.61 | 71.01 | 60.34 | 53.40 | 48.47 | 44.75 |
| | 116.00 | 86.35 | 70.74 | 81.60 | 55.57 | 51.18 | 47.77 |
| | 118.00 | 82.88 | 69.15 | 61.39 | 56.18 | 52.30 | 49.23 |
| | 120.00 | 79.10 | 68.13 | 61.76 | 57.32 | 53.89 | 51.10 |
| | 122.00 | 74.60 | 66.76 | 61.76 | 58.05 | 55.07 | 52.56 |
| | 124.00 | 68.94 | 64.73 | 61.11 | 58.13 | 55.59 | 53.38 |
| | 126.00 | 61.71 | 61.64 | 59.51 | 57.31 | 55.25 | 53.35 |
| | 128.00 | 54.71 | 58.74 | 58.12 | 56.68 | 55.09 | 53.48 |
| | 130.00 | 48.61 | 56.15 | 56.98 | 56.27 | 55.08 | 53.75 |
| | 132.00 | 43.80 | 53.95 | 56.13 | 56.11 | 55.32 | 54.24 |
| | 134.00 | 40.44 | 52.25 | 55.62 | 56.22 | 55.80 | 54.95 |
| | 136.00 | 35.56 | 48.72 | 53.45 | 54.83 | 54.89 | 54.36 |
| | 138.00 | 31.71 | 45.48 | 51.48 | 53.54 | 54.06 | 53.84 |
| | 140.00 | 28.72 | 42.60 | 49.51 | 52.35 | 53.32 | 53.40 |

Table E-10--continued

| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| | | % Retention | | | | | |
| 160.00 | 110.00 | 93.82 | 76.83 | 64.72 | 56.69 | 51.06 | 46.88 |
| | 112.00 | 92.81 | 77.47 | 67.14 | 60.24 | 55.29 | 51.54 |
| | 114.00 | 91.31 | 77.30 | 68.40 | 62.41 | 58.85 | 54.67 |
| | 116.00 | 89.54 | 77.05 | 69.45 | 64.29 | 60.45 | 57.42 |
| | 118.00 | 86.72 | 75.71 | 69.25 | 64.80 | 61.43 | 58.71 |
| | 120.00 | 83.71 | 74.82 | 69.53 | 65.77 | 62.82 | 60.38 |
| | 122.00 | 79.93 | 73.62 | 69.49 | 66.37 | 63.83 | 61.60 |
| | 124.00 | 75.01 | 71.82 | 68.89 | 66.42 | 64.26 | 62.36 |
| | 126.00 | 68.47 | 69.09 | 67.47 | 65.68 | 63.94 | 62.32 |
| | 128.00 | 61.74 | 68.46 | 66.21 | 65.10 | 62.77 | 63.42 |
| | 130.00 | 55.44 | 64.01 | 65.34 | 64.70 | 63.75 | 62.64 |
| | 132.00 | 50.14 | 61.84 | 64.31 | 64.51 | 65.93 | 63.06 |
| | 134.00 | 46.14 | 60.05 | 63.75 | 64.55 | 64.32 | 63.66 |
| | 136.00 | 40.67 | 56.53 | 61.72 | 63.28 | 63.49 | 63.12 |
| | 138.00 | 36.27 | 53.19 | 59.75 | 62.07 | 62.73 | 62.64 |
| | 140.00 | 32.83 | 58.10 | 57.89 | 60.94 | 62.83 | 62.22 |
| 200.00 | 110.00 | 95.02 | 88.98 | 78.59 | 63.49 | 58.39 | 54.54 |
| | 112.00 | 94.20 | 81.51 | 72.69 | 66.64 | 62.23 | 58.83 |
| | 114.00 | 92.98 | 81.36 | 73.76 | 68.56 | 64.69 | 61.67 |
| | 116.00 | 91.52 | 81.13 | 74.66 | 70.19 | 66.82 | 64.13 |
| | 118.00 | 89.18 | 79.98 | 74.47 | 70.65 | 67.68 | 65.28 |
| | 120.00 | 86.65 | 79.20 | 74.70 | 71.46 | 68.89 | 66.75 |
| | 122.00 | 83.42 | 78.14 | 74.64 | 71.97 | 69.77 | 67.88 |
| | 124.00 | 79.11 | 76.56 | 74.10 | 72.00 | 70.14 | 68.49 |
| | 126.00 | 73.72 | 74.14 | 72.84 | 71.34 | 69.85 | 68.45 |
| | 128.00 | 68.48 | 71.77 | 71.71 | 70.81 | 69.69 | 68.53 |
| | 130.00 | 60.65 | 69.51 | 70.73 | 70.44 | 69.64 | 68.71 |
| | 132.00 | 55.13 | 67.46 | 69.95 | 70.25 | 69.80 | 69.07 |
| | 134.00 | 50.72 | 65.69 | 69.41 | 70.25 | 70.12 | 69.59 |
| | 136.00 | 44.85 | 62.31 | 67.53 | 69.10 | 69.38 | 69.10 |
| | 138.00 | 40.00 | 59.02 | 65.70 | 68.00 | 68.69 | 68.67 |
| | 140.00 | 36.16 | 55.89 | 63.93 | 68.96 | 68.05 | 68.29 |
| 240.00 | 110.00 | 95.83 | 83.87 | 74.80 | 68.47 | 63.86 | 60.33 |
| | 112.00 | 95.14 | 84.33 | 76.64 | 71.29 | 67.33 | 64.26 |
| | 114.00 | 94.11 | 84.19 | 77.58 | 72.99 | 69.55 | 66.83 |
| | 116.00 | 92.87 | 83.95 | 78.36 | 74.44 | 71.45 | 69.04 |
| | 118.00 | 90.98 | 82.98 | 78.19 | 74.82 | 72.21 | 70.08 |
| | 120.00 | 88.69 | 82.29 | 78.38 | 75.54 | 73.28 | 71.38 |
| | 122.00 | 85.88 | 81.35 | 78.32 | 75.99 | 74.05 | 72.38 |
| | 124.00 | 82.06 | 79.94 | 77.83 | 76.00 | 74.38 | 72.92 |
| | 126.00 | 76.73 | 77.78 | 76.70 | 75.41 | 74.11 | 72.88 |
| | 128.00 | 70.81 | 75.64 | 75.68 | 74.93 | 73.96 | 72.95 |
| | 130.00 | 64.77 | 73.57 | 74.79 | 74.59 | 73.93 | 73.11 |
| | 132.00 | 59.18 | 71.65 | 74.07 | 74.40 | 74.05 | 73.42 |
| | 134.00 | 54.52 | 69.95 | 73.55 | 74.39 | 74.32 | 73.87 |
| | 136.00 | 48.37 | 64.75 | 71.83 | 73.35 | 73.65 | 73.43 |
| | 138.00 | 43.18 | 63.57 | 70.14 | 72.34 | 73.02 | 73.04 |
| | 140.00 | 39.00 | 60.48 | 68.48 | 71.39 | 72.44 | 72.69 |

Table E-11 Simulated quality retention of foods with thermal diffusivity 1.4 x 10$^{-7}$ m$^2$/s after thermal processing in the conically shaped container #2 using Infinite h

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| D (mm) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 40.00 | 110.00 | 78.60 | 37.56 | 29.04 | 12.34 | 8.42 | 6.17 |
| | 112.00 | 75.46 | 38.88 | 23.09 | 15.56 | 11.39 | 8.82 |
| | 114.00 | 71.61 | 39.45 | 25.48 | 18.34 | 14.13 | 11.40 |
| | 116.00 | 66.59 | 38.95 | 26.84 | 20.30 | 16.23 | 13.47 |
| | 118.00 | 61.64 | 38.83 | 28.42 | 22.44 | 18.52 | 15.74 |
| | 120.00 | 55.03 | 37.23 | 28.61 | 23.35 | 19.75 | 17.10 |
| | 122.00 | 47.62 | 34.93 | 28.08 | 23.61 | 20.39 | 17.94 |
| | 124.00 | 41.65 | 33.48 | 28.13 | 24.30 | 21.38 | 19.06 |
| | 126.00 | 34.99 | 30.83 | 27.03 | 23.96 | 21.45 | 19.38 |
| | 128.00 | 30.10 | 28.86 | 26.34 | 23.92 | 21.77 | 19.90 |
| | 130.00 | 26.95 | 27.60 | 26.10 | 24.21 | 22.35 | 20.48 |
| | 132.00 | 25.33 | 27.09 | 26.34 | 24.87 | 23.26 | 21.69 |
| | 134.00 | 21.73 | 24.57 | 24.71 | 23.84 | 22.62 | 21.32 |
| | 136.00 | 18.98 | 22.53 | 23.35 | 22.98 | 22.11 | 21.05 |
| | 138.00 | 16.90 | 20.94 | 22.26 | 22.30 | 21.73 | 20.89 |
| | 140.00 | 15.38 | 19.77 | 21.43 | 21.80 | 21.47 | 20.80 |
| 80.00 | 110.00 | 88.63 | 61.13 | 44.57 | 34.97 | 28.89 | 24.74 |
| | 112.00 | 86.81 | 62.11 | 47.78 | 39.21 | 33.56 | 29.56 |
| | 114.00 | 84.48 | 62.44 | 50.09 | 42.51 | 37.34 | 33.57 |
| | 116.00 | 81.30 | 61.85 | 51.29 | 44.64 | 39.97 | 36.45 |
| | 118.00 | 77.89 | 61.51 | 52.62 | 46.83 | 42.63 | 39.37 |
| | 120.00 | 72.97 | 59.88 | 52.60 | 47.66 | 43.94 | 40.98 |
| | 122.00 | 66.78 | 57.54 | 51.87 | 47.78 | 44.56 | 41.91 |
| | 124.00 | 60.82 | 55.76 | 51.64 | 48.32 | 45.54 | 43.15 |
| | 126.00 | 53.45 | 52.77 | 50.27 | 47.78 | 45.50 | 43.43 |
| | 128.00 | 47.00 | 50.20 | 49.24 | 47.53 | 45.71 | 43.93 |
| | 130.00 | 41.97 | 48.16 | 48.58 | 47.59 | 46.19 | 44.68 |
| | 132.00 | 38.57 | 48.75 | 48.37 | 48.81 | 47.97 | 45.69 |
| | 134.00 | 33.43 | 43.28 | 46.25 | 46.68 | 46.14 | 45.18 |
| | 136.00 | 29.46 | 40.19 | 44.32 | 45.49 | 45.41 | 44.78 |
| | 138.00 | 26.45 | 37.54 | 42.60 | 44.45 | 44.84 | 44.48 |
| | 140.00 | 24.21 | 35.34 | 41.12 | 43.57 | 44.32 | 44.24 |
| 120.00 | 110.00 | 92.26 | 71.99 | 58.30 | 49.58 | 43.66 | 39.37 |
| | 112.00 | 91.99 | 72.73 | 61.04 | 53.50 | 48.23 | 44.33 |
| | 114.00 | 89.34 | 72.95 | 62.96 | 56.44 | 51.78 | 48.24 |
| | 116.00 | 87.04 | 72.45 | 63.93 | 58.29 | 54.16 | 50.95 |
| | 118.00 | 84.50 | 72.11 | 64.98 | 60.15 | 56.52 | 53.62 |
| | 120.00 | 81.73 | 70.72 | 64.90 | 60.82 | 57.65 | 55.06 |
| | 122.00 | 75.76 | 68.73 | 64.23 | 60.87 | 58.16 | 55.87 |
| | 124.00 | 71.61 | 67.12 | 63.95 | 61.29 | 58.98 | 56.95 |
| | 126.00 | 63.84 | 64.45 | 62.70 | 60.77 | 58.93 | 57.17 |
| | 128.00 | 57.29 | 62.02 | 61.71 | 60.49 | 59.05 | 57.59 |
| | 130.00 | 51.63 | 59.95 | 61.01 | 60.47 | 59.42 | 58.21 |
| | 132.00 | 47.30 | 58.33 | 60.66 | 60.74 | 60.04 | 59.06 |
| | 134.00 | 41.29 | 54.81 | 58.64 | 59.50 | 59.27 | 58.58 |
| | 136.00 | 36.43 | 51.49 | 56.74 | 58.36 | 58.58 | 58.19 |
| | 138.00 | 32.48 | 48.47 | 54.97 | 57.33 | 57.99 | 57.98 |
| | 140.00 | 29.88 | 45.81 | 53.37 | 56.41 | 57.49 | 57.64 |

Table E- 11—continued

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| θ (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 160.00 | 110.00 | 94.14 | 78.14 | 66.69 | 59.06 | 53.69 | 49.69 |
| | 112.00 | 93.15 | 78.73 | 69.03 | 62.52 | 57.85 | 54.30 |
| | 114.00 | 91.88 | 78.90 | 70.66 | 65.07 | 61.90 | 57.85 |
| | 116.00 | 90.08 | 78.46 | 71.43 | 66.65 | 63.09 | 60.27 |
| | 118.00 | 88.07 | 78.18 | 72.29 | 66.23 | 65.13 | 62.82 |
| | 120.00 | 85.03 | 76.99 | 72.20 | 68.78 | 66.10 | 63.87 |
| | 122.00 | 80.93 | 75.29 | 71.60 | 66.81 | 66.52 | 64.57 |
| | 124.00 | 76.51 | 73.89 | 71.33 | 69.14 | 67.21 | 65.49 |
| | 126.00 | 70.47 | 71.55 | 70.24 | 66.68 | 67.13 | 65.87 |
| | 128.00 | 64.26 | 69.37 | 69.34 | 68.41 | 67.23 | 66.02 |
| | 130.00 | 58.49 | 67.44 | 68.68 | 68.35 | 67.53 | 66.54 |
| | 132.00 | 53.72 | 65.85 | 66.31 | 69.55 | 66.85 | 67.25 |
| | 134.00 | 47.23 | 62.52 | 66.49 | 67.45 | 67.36 | 66.83 |
| | 136.00 | 41.78 | 59.27 | 64.73 | 66.41 | 66.74 | 66.47 |
| | 138.00 | 37.45 | 56.20 | 63.06 | 65.47 | 66.20 | 66.19 |
| | 140.00 | 34.15 | 53.78 | 61.51 | 64.61 | 65.73 | 65.96 |
| 200.00 | 110.00 | 95.28 | 82.08 | 72.31 | 65.61 | 60.79 | 57.14 |
| | 112.00 | 94.48 | 82.56 | 74.32 | 66.66 | 64.51 | 61.34 |
| | 114.00 | 93.44 | 82.71 | 75.70 | 70.89 | 67.32 | 64.53 |
| | 116.00 | 91.97 | 82.33 | 76.37 | 72.26 | 69.15 | 66.68 |
| | 118.00 | 90.31 | 82.06 | 77.10 | 73.82 | 70.93 | 68.74 |
| | 120.00 | 87.77 | 81.05 | 77.01 | 74.19 | 71.77 | 69.83 |
| | 122.00 | 84.29 | 79.59 | 76.48 | 74.10 | 72.13 | 70.44 |
| | 124.00 | 80.44 | 78.38 | 76.23 | 74.37 | 72.72 | 71.24 |
| | 126.00 | 75.05 | 76.31 | 75.26 | 73.96 | 72.65 | 71.39 |
| | 128.00 | 69.28 | 74.36 | 74.46 | 73.71 | 72.72 | 71.89 |
| | 130.00 | 63.64 | 72.59 | 73.66 | 73.64 | 72.97 | 72.13 |
| | 132.00 | 58.70 | 71.09 | 73.49 | 73.73 | 73.40 | 72.75 |
| | 134.00 | 51.98 | 68.01 | 71.46 | 72.81 | 72.79 | 72.37 |
| | 136.00 | 46.13 | 64.93 | 70.26 | 71.89 | 72.24 | 72.05 |
| | 138.00 | 41.35 | 61.96 | 66.72 | 71.03 | 71.78 | 71.80 |
| | 140.00 | 37.63 | 59.12 | 67.27 | 70.25 | 71.33 | 71.58 |
| 240.00 | 110.00 | 96.05 | 84.82 | 78.32 | 70.38 | 66.84 | 62.72 |
| | 112.00 | 95.38 | 85.25 | 78.08 | 73.09 | 69.41 | 66.54 |
| | 114.00 | 94.50 | 85.35 | 75.28 | 75.06 | 71.90 | 69.41 |
| | 116.00 | 93.25 | 85.03 | 79.86 | 76.26 | 73.53 | 71.32 |
| | 118.00 | 91.84 | 84.78 | 80.49 | 77.45 | 75.09 | 73.16 |
| | 120.00 | 89.66 | 83.90 | 80.40 | 77.86 | 75.83 | 74.12 |
| | 122.00 | 88.64 | 82.82 | 79.93 | 77.86 | 76.14 | 74.66 |
| | 124.00 | 83.25 | 81.53 | 79.70 | 78.09 | 76.66 | 75.36 |
| | 126.00 | 78.41 | 79.71 | 78.84 | 77.72 | 76.59 | 75.49 |
| | 128.00 | 73.07 | 77.96 | 78.12 | 77.50 | 76.65 | 75.75 |
| | 130.00 | 67.65 | 76.35 | 77.57 | 77.43 | 76.66 | 76.14 |
| | 132.00 | 62.69 | 74.95 | 77.23 | 77.55 | 77.23 | 76.67 |
| | 134.00 | 55.89 | 72.11 | 75.76 | 76.67 | 76.69 | 76.34 |
| | 136.00 | 49.79 | 69.23 | 74.31 | 75.84 | 76.20 | 76.05 |
| | 138.00 | 44.67 | 66.37 | 72.90 | 75.07 | 75.76 | 75.82 |
| | 140.00 | 40.66 | 63.61 | 71.54 | 74.35 | 75.37 | 75.63 |

Table E.12 Simulated quality retention of foods with thermal diffusivity 1.6 x $10^{-7}$ $m^2/s$ after thermal processing in the conically shaped container #2 using Infinite h

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 40.00 | 110.00 | 79.37 | 39.41 | 21.84 | 13.90 | 9.74 | 7.31 |
| | 112.00 | 76.64 | 41.28 | 25.51 | 17.75 | 13.35 | 10.58 |
| | 114.00 | 71.40 | 42.58 | 28.57 | 21.24 | 16.80 | 13.84 |
| | 116.00 | 68.12 | 41.45 | 29.51 | 22.93 | 18.75 | 15.87 |
| | 118.00 | 63.88 | 41.97 | 31.71 | 25.68 | 21.64 | 18.72 |
| | 120.00 | 56.16 | 39.20 | 30.90 | 25.78 | 22.20 | 19.52 |
| | 122.00 | 51.39 | 39.19 | 32.39 | 27.83 | 24.48 | 21.87 |
| | 124.00 | 43.51 | 36.18 | 31.15 | 27.45 | 24.56 | 22.23 |
| | 126.00 | 37.06 | 33.83 | 30.35 | 27.40 | 24.92 | 22.83 |
| | 128.00 | 32.44 | 32.21 | 30.02 | 27.72 | 25.59 | 23.70 |
| | 130.00 | 29.09 | 31.39 | 30.23 | 28.45 | 26.61 | 24.87 |
| | 132.00 | 25.03 | 28.41 | 28.41 | 27.33 | 25.92 | 24.47 |
| | 134.00 | 21.53 | 25.95 | 26.88 | 26.42 | 25.41 | 24.23 |
| | 136.00 | 18.97 | 24.81 | 25.64 | 25.70 | 25.05 | 24.11 |
| | 138.00 | 17.13 | 22.55 | 24.69 | 25.18 | 24.85 | 24.12 |
| | 140.00 | 15.91 | 21.55 | 24.04 | 24.98 | 24.81 | 24.28 |
| 80.00 | 110.00 | 89.07 | 62.66 | 46.58 | 37.14 | 31.11 | 26.95 |
| | 112.00 | 87.50 | 64.06 | 50.28 | 41.94 | 36.38 | 32.40 |
| | 114.00 | 85.56 | 64.90 | 53.14 | 45.82 | 40.77 | 37.04 |
| | 116.00 | 82.29 | 63.94 | 53.98 | 47.54 | 43.04 | 39.63 |
| | 118.00 | 79.43 | 64.12 | 55.74 | 50.23 | 46.18 | 43.01 |
| | 120.00 | 73.93 | 61.67 | 54.86 | 50.22 | 46.71 | 43.88 |
| | 122.00 | 69.85 | 61.31 | 55.98 | 52.08 | 48.98 | 46.40 |
| | 124.00 | 62.75 | 58.39 | 54.65 | 51.58 | 48.98 | 46.73 |
| | 126.00 | 55.82 | 55.82 | 53.64 | 51.37 | 49.24 | 47.29 |
| | 128.00 | 49.80 | 53.72 | 53.02 | 51.49 | 49.79 | 48.11 |
| | 130.00 | 45.24 | 52.22 | 52.85 | 51.98 | 50.66 | 49.22 |
| | 132.00 | 38.83 | 48.59 | 50.76 | 50.70 | 49.86 | 48.73 |
| | 134.00 | 33.70 | 45.26 | 48.84 | 49.57 | 49.21 | 48.39 |
| | 136.00 | 29.80 | 42.33 | 47.12 | 48.59 | 48.69 | 48.17 |
| | 138.00 | 26.96 | 39.85 | 45.63 | 47.78 | 48.31 | 48.08 |
| | 140.00 | 24.98 | 37.85 | 44.41 | 47.16 | 48.09 | 48.12 |
| 120.00 | 110.00 | 92.57 | 73.19 | 60.05 | 51.63 | 45.88 | 41.66 |
| | 112.00 | 91.47 | 74.26 | 63.17 | 55.97 | 50.91 | 47.14 |
| | 114.00 | 90.10 | 74.88 | 65.52 | 59.36 | 54.92 | 51.53 |
| | 116.00 | 87.76 | 74.80 | 66.11 | 60.81 | 56.92 | 53.89 |
| | 118.00 | 85.64 | 74.19 | 67.57 | 63.06 | 59.65 | 56.90 |
| | 120.00 | 81.50 | 72.20 | 66.81 | 63.03 | 60.18 | 57.65 |
| | 122.00 | 78.21 | 71.80 | 67.66 | 64.54 | 61.99 | 59.82 |
| | 124.00 | 72.31 | 69.35 | 66.50 | 64.08 | 61.97 | 60.09 |
| | 126.00 | 66.07 | 67.09 | 65.59 | 63.86 | 62.15 | 60.55 |
| | 128.00 | 60.08 | 65.13 | 64.98 | 63.90 | 62.58 | 61.23 |
| | 130.00 | 54.98 | 63.60 | 64.72 | 64.25 | 63.28 | 62.15 |
| | 132.00 | 47.91 | 60.17 | 62.83 | 63.11 | 62.57 | 61.71 |
| | 134.00 | 41.88 | 56.86 | 61.04 | 62.07 | 61.97 | 61.40 |
| | 136.00 | 37.08 | 53.76 | 59.38 | 61.15 | 61.48 | 61.18 |
| | 138.00 | 33.44 | 50.97 | 57.87 | 60.36 | 61.10 | 61.06 |
| | 140.00 | 30.84 | 48.55 | 56.55 | 59.71 | 60.85 | 61.06 |

Table E- 12--continued

| D (min) | Temp(°C) | % Retention<br>Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| 160.00 | 110.00 | 94.37 | 79.12 | 68.19 | 60.89 | 55.73 | 51.87 |
| | 112.00 | 93.53 | 79.97 | 70.83 | 64.69 | 60.25 | 56.87 |
| | 114.00 | 92.47 | 80.46 | 72.79 | 67.59 | 63.77 | 60.80 |
| | 116.00 | 90.65 | 79.82 | 73.27 | 68.82 | 65.50 | 62.87 |
| | 118.00 | 88.98 | 79.86 | 74.46 | 70.71 | 67.83 | 65.48 |
| | 120.00 | 85.67 | 78.22 | 73.81 | 70.67 | 68.19 | 66.13 |
| | 122.00 | 82.95 | 77.85 | 74.49 | 71.92 | 69.80 | 67.98 |
| | 124.00 | 77.99 | 75.78 | 73.50 | 71.52 | 69.77 | 68.21 |
| | 126.00 | 72.49 | 73.82 | 72.71 | 71.31 | 69.92 | 68.58 |
| | 128.00 | 66.66 | 72.08 | 72.15 | 71.33 | 70.26 | 69.15 |
| | 130.00 | 61.74 | 70.68 | 71.66 | 71.59 | 70.84 | 69.92 |
| | 132.00 | 54.53 | 67.56 | 70.22 | 70.60 | 70.22 | 69.53 |
| | 134.00 | 48.05 | 64.47 | 66.62 | 69.69 | 69.69 | 69.25 |
| | 136.00 | 42.65 | 61.48 | 67.11 | 68.86 | 69.25 | 69.05 |
| | 138.00 | 38.41 | 58.68 | 65.70 | 68.14 | 66.90 | 68.94 |
| | 140.00 | 35.27 | 56.14 | 64.44 | 67.53 | 68.65 | 68.92 |
| 200.00 | 110.00 | 95.47 | 82.91 | 73.61 | 67.23 | 62.63 | 59.14 |
| | 112.00 | 94.79 | 83.62 | 75.88 | 70.56 | 66.67 | 63.68 |
| | 114.00 | 93.93 | 84.02 | 77.54 | 73.00 | 69.76 | 67.15 |
| | 116.00 | 92.43 | 83.47 | 77.95 | 74.14 | 71.26 | 68.97 |
| | 118.00 | 91.05 | 83.50 | 78.95 | 75.76 | 73.28 | 71.25 |
| | 120.00 | 88.31 | 82.10 | 78.39 | 75.72 | 73.59 | 71.81 |
| | 122.00 | 86.00 | 81.77 | 78.95 | 76.78 | 74.97 | 73.41 |
| | 124.00 | 81.74 | 79.99 | 78.10 | 76.43 | 74.94 | 73.59 |
| | 126.00 | 76.87 | 78.28 | 77.40 | 76.24 | 75.06 | 73.92 |
| | 128.00 | 71.71 | 76.74 | 76.90 | 76.24 | 75.35 | 74.41 |
| | 130.00 | 66.74 | 75.44 | 76.64 | 76.45 | 75.83 | 75.06 |
| | 132.00 | 59.63 | 72.65 | 75.18 | 75.38 | 75.29 | 74.73 |
| | 134.00 | 52.95 | 69.83 | 73.76 | 74.78 | 74.83 | 74.48 |
| | 136.00 | 47.16 | 67.02 | 72.39 | 74.04 | 74.44 | 74.30 |
| | 138.00 | 42.47 | 64.32 | 71.11 | 73.39 | 74.12 | 74.19 |
| | 140.00 | 38.89 | 61.68 | 69.93 | 72.84 | 73.90 | 74.17 |
| 240.00 | 110.00 | 96.21 | 85.53 | 77.46 | 71.83 | 67.71 | 64.55 |
| | 112.00 | 95.64 | 86.14 | 79.44 | 74.77 | 71.32 | 68.63 |
| | 114.00 | 94.91 | 86.49 | 80.89 | 76.99 | 74.07 | 71.75 |
| | 116.00 | 93.65 | 86.01 | 81.24 | 77.92 | 75.39 | 73.37 |
| | 118.00 | 92.47 | 86.03 | 82.11 | 79.33 | 77.17 | 75.38 |
| | 120.00 | 90.12 | 84.81 | 81.61 | 79.29 | 77.43 | 75.87 |
| | 122.00 | 86.13 | 84.52 | 82.09 | 80.21 | 78.64 | 77.28 |
| | 124.00 | 84.48 | 82.95 | 81.34 | 79.90 | 78.61 | 77.44 |
| | 126.00 | 80.66 | 81.45 | 80.72 | 79.73 | 78.71 | 77.72 |
| | 128.00 | 75.32 | 80.87 | 80.27 | 79.72 | 78.96 | 78.14 |
| | 130.00 | 70.58 | 78.89 | 80.03 | 79.90 | 79.28 | 78.71 |
| | 132.00 | 63.68 | 76.38 | 78.73 | 79.13 | 78.90 | 78.42 |
| | 134.00 | 56.86 | 73.79 | 77.46 | 78.41 | 78.49 | 78.20 |
| | 136.00 | 50.94 | 71.18 | 76.23 | 77.76 | 78.14 | 78.03 |
| | 138.00 | 45.91 | 68.62 | 75.06 | 77.17 | 77.85 | 77.96 |
| | 140.00 | 41.98 | 66.18 | 73.87 | 76.66 | 77.65 | 77.91 |

Table E- 13 Simulated quality retention of foods with thermal diffusivity 1.2 x $10^{-7}$ $m^2/s$ after thermal processing in the conically shaped container #3, h = 300 $w/m^2K$

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| **D (min)** | **Temp(°C)** | **Z = 10°C** | **Z = 20°C** | **Z = 30°C** | **Z = 40°C** | **Z = 50°C** | **Z = 60°C** |
| 40.00 | 110.00 | 75.73 | 29.73 | 12.70 | 6.38 | 3.63 | 2.26 |
| | 112.00 | 71.85 | 30.08 | 14.36 | 7.95 | 4.89 | 3.25 |
| | 114.00 | 67.21 | 29.88 | 15.61 | 9.31 | 6.08 | 4.24 |
| | 116.00 | 62.42 | 29.83 | 16.90 | 10.75 | 7.38 | 5.34 |
| | 118.00 | 56.24 | 28.63 | 17.26 | 11.52 | 8.21 | 6.12 |
| | 120.00 | 50.12 | 27.51 | 17.57 | 12.23 | 8.59 | 6.88 |
| | 122.00 | 42.77 | 25.18 | 16.87 | 12.15 | 9.17 | 7.16 |
| | 124.00 | 38.46 | 24.73 | 17.43 | 13.00 | 10.07 | 8.02 |
| | 126.00 | 32.77 | 22.64 | 16.63 | 12.77 | 10.10 | 8.18 |
| | 128.00 | 28.58 | 21.14 | 16.16 | 12.73 | 10.27 | 8.43 |
| | 130.00 | 25.75 | 20.21 | 16.01 | 12.93 | 10.61 | 8.84 |
| | 132.00 | 22.26 | 18.43 | 15.09 | 12.46 | 10.41 | 8.79 |
| | 134.00 | 21.52 | 18.52 | 15.56 | 13.09 | 11.08 | 9.46 |
| | 136.00 | 19.70 | 17.59 | 15.14 | 12.97 | 11.13 | 9.60 |
| | 138.00 | 16.62 | 15.49 | 13.71 | 11.97 | 10.42 | 9.09 |
| | 140.00 | 15.93 | 15.21 | 13.70 | 12.12 | 10.67 | 9.39 |
| 80.00 | 110.00 | 86.96 | 54.15 | 35.21 | 24.92 | 18.80 | 14.86 |
| | 112.00 | 84.62 | 54.28 | 37.31 | 27.72 | 21.77 | 17.77 |
| | 114.00 | 81.68 | 53.85 | 38.71 | 29.89 | 24.28 | 20.24 |
| | 116.00 | 78.40 | 53.46 | 40.87 | 31.98 | 26.56 | 22.67 |
| | 118.00 | 73.82 | 51.93 | 40.23 | 32.95 | 27.92 | 24.21 |
| | 120.00 | 68.70 | 50.35 | 40.28 | 33.77 | 29.11 | 25.59 |
| | 122.00 | 61.87 | 47.45 | 39.09 | 33.44 | 29.26 | 26.01 |
| | 124.00 | 56.72 | 46.27 | 39.36 | 34.37 | 30.53 | 27.44 |
| | 126.00 | 48.85 | 43.32 | 37.98 | 33.79 | 30.41 | 27.61 |
| | 128.00 | 44.08 | 40.86 | 36.93 | 33.46 | 30.49 | 27.93 |
| | 130.00 | 39.65 | 38.96 | 36.25 | 33.43 | 30.82 | 28.49 |
| | 132.00 | 34.67 | 36.06 | 34.58 | 32.47 | 30.30 | 28.26 |
| | 134.00 | 32.72 | 35.38 | 34.63 | 32.99 | 31.18 | 29.21 |
| | 136.00 | 29.83 | 33.41 | 33.58 | 32.48 | 30.94 | 29.29 |
| | 138.00 | 25.71 | 30.17 | 31.21 | 30.75 | 29.65 | 28.31 |
| | 140.00 | 24.29 | 29.14 | 30.67 | 30.61 | 29.78 | 28.82 |
| 120.00 | 110.00 | 91.09 | 66.34 | 49.73 | 39.47 | 32.71 | 27.97 |
| | 112.00 | 89.43 | 66.39 | 51.63 | 42.35 | 36.05 | 31.50 |
| | 114.00 | 87.30 | 65.95 | 52.87 | 44.49 | 38.66 | 34.34 |
| | 116.00 | 84.87 | 65.54 | 54.02 | 46.49 | 41.11 | 37.02 |
| | 118.00 | 81.37 | 64.13 | 54.87 | 47.37 | 42.45 | 38.64 |
| | 120.00 | 77.27 | 62.64 | 54.01 | 48.08 | 43.62 | 40.07 |
| | 122.00 | 71.51 | 59.96 | 52.80 | 47.68 | 43.71 | 40.48 |
| | 124.00 | 66.69 | 58.67 | 52.90 | 48.45 | 44.91 | 41.92 |
| | 126.00 | 59.98 | 55.75 | 51.46 | 47.83 | 44.73 | 42.04 |
| | 128.00 | 53.80 | 53.15 | 50.29 | 47.40 | 44.74 | 42.33 |
| | 130.00 | 48.64 | 50.97 | 49.44 | 47.25 | 44.99 | 42.84 |
| | 132.00 | 42.90 | 47.77 | 47.62 | 46.18 | 44.30 | 42.55 |
| | 134.00 | 40.16 | 46.54 | 47.41 | 46.54 | 45.09 | 43.45 |
| | 136.00 | 36.57 | 44.19 | 46.12 | 45.89 | 44.83 | 43.46 |
| | 138.00 | 31.83 | 40.47 | 43.50 | 44.02 | 43.45 | 42.41 |
| | 140.00 | 29.88 | 38.52 | 42.66 | 43.69 | 43.47 | 42.66 |

Table E- 13—continued.

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| D (mm) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 160.00 | 110.00 | 93.24 | 73.46 | 59.16 | 49.74 | 43.28 | 38.42 |
| | 112.00 | 91.95 | 73.48 | 60.83 | 52.42 | 46.46 | 41.99 |
| | 114.00 | 90.29 | 73.09 | 61.89 | 54.37 | 48.94 | 44.79 |
| | 116.00 | 88.36 | 72.70 | 62.86 | 56.17 | 51.23 | 47.38 |
| | 118.00 | 85.55 | 71.46 | 62.87 | 56.94 | 52.47 | 48.92 |
| | 120.00 | 82.17 | 70.13 | 62.76 | 57.55 | 53.52 | 50.25 |
| | 122.00 | 77.29 | 67.75 | 61.64 | 57.15 | 53.58 | 50.62 |
| | 124.00 | 72.96 | 66.51 | 61.66 | 57.84 | 54.66 | 51.94 |
| | 126.00 | 66.72 | 63.81 | 60.30 | 57.19 | 54.46 | 52.04 |
| | 128.00 | 60.60 | 61.33 | 59.16 | 56.75 | 54.44 | 52.28 |
| | 130.00 | 55.16 | 59.15 | 58.29 | 56.35 | 54.65 | 52.73 |
| | 132.00 | 49.02 | 55.97 | 56.52 | 55.51 | 54.04 | 52.44 |
| | 134.00 | 45.73 | 54.53 | 56.19 | 55.77 | 54.03 | 53.24 |
| | 136.00 | 41.66 | 52.01 | 54.85 | 55.09 | 54.35 | 53.22 |
| | 138.00 | 36.48 | 48.13 | 52.26 | 53.27 | 53.02 | 52.21 |
| | 140.00 | 34.14 | 46.27 | 51.28 | 52.87 | 52.98 | 52.40 |
| 200.00 | 110.00 | 94.55 | 78.11 | 65.67 | 57.16 | 51.07 | 46.50 |
| | 112.00 | 93.50 | 78.12 | 67.14 | 59.60 | 54.12 | 49.92 |
| | 114.00 | 92.14 | 77.77 | 68.06 | 61.38 | 56.41 | 52.56 |
| | 116.00 | 90.54 | 77.41 | 68.90 | 62.97 | 58.51 | 54.97 |
| | 118.00 | 88.20 | 76.32 | 68.88 | 63.94 | 59.83 | 56.30 |
| | 120.00 | 85.33 | 75.14 | 68.76 | 64.17 | 60.57 | 57.60 |
| | 122.00 | 81.12 | 73.02 | 67.74 | 63.80 | 60.61 | 57.93 |
| | 124.00 | 77.25 | 71.88 | 67.72 | 64.38 | 61.57 | 59.13 |
| | 126.00 | 71.54 | 69.43 | 66.47 | 63.78 | 61.37 | 59.21 |
| | 128.00 | 65.66 | 67.12 | 65.41 | 63.36 | 61.33 | 59.42 |
| | 130.00 | 60.16 | 65.03 | 64.56 | 63.14 | 61.48 | 59.81 |
| | 132.00 | 53.64 | 61.99 | 62.90 | 62.18 | 60.93 | 59.53 |
| | 134.00 | 50.17 | 60.48 | 62.52 | 62.35 | 61.44 | 60.24 |
| | 136.00 | 45.76 | 57.93 | 61.21 | 61.69 | 61.15 | 60.21 |
| | 138.00 | 40.26 | 54.05 | 58.74 | 59.99 | 59.91 | 59.27 |
| | 140.00 | 37.58 | 52.03 | 57.72 | 59.56 | 59.84 | 59.42 |
| 240.00 | 110.00 | 95.43 | 81.38 | 70.42 | 62.72 | 57.10 | 52.81 |
| | 112.00 | 94.55 | 81.38 | 71.72 | 64.94 | 59.93 | 56.03 |
| | 114.00 | 93.40 | 81.07 | 72.53 | 66.53 | 62.03 | 58.48 |
| | 116.00 | 92.54 | 80.74 | 73.26 | 67.98 | 63.94 | 60.70 |
| | 118.00 | 90.03 | 79.79 | 73.24 | 68.57 | 64.95 | 62.00 |
| | 120.00 | 87.54 | 78.71 | 73.12 | 69.04 | 65.80 | 63.11 |
| | 122.00 | 83.85 | 76.83 | 72.19 | 68.68 | 65.83 | 63.40 |
| | 124.00 | 80.37 | 75.78 | 72.14 | 69.19 | 66.69 | 64.49 |
| | 126.00 | 75.14 | 73.55 | 71.00 | 68.64 | 66.50 | 64.56 |
| | 128.00 | 69.57 | 71.41 | 70.01 | 68.24 | 66.45 | 64.74 |
| | 130.00 | 64.15 | 69.45 | 69.22 | 68.02 | 66.57 | 65.09 |
| | 132.00 | 57.70 | 66.58 | 67.67 | 67.12 | 66.05 | 64.82 |
| | 134.00 | 53.84 | 65.07 | 67.28 | 67.26 | 66.50 | 65.46 |
| | 136.00 | 49.18 | 62.57 | 66.03 | 66.63 | 66.23 | 65.42 |
| | 138.00 | 43.44 | 58.77 | 63.70 | 65.05 | 65.08 | 64.55 |
| | 140.00 | 40.49 | 56.67 | 62.68 | 64.62 | 64.99 | 64.68 |

Table E- 14 Simulated quality retention of foods with thermal diffusivity 1.4 x 10$^{-7}$ m$^2$/s after thermal processing in the conically shaped container #3 h = 300 w/m$^2$K

| D (min) | Temp(°C) | % Retention<br>Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| 40.00 | 110.00 | 76.91 | 32.13 | 14.64 | 7.80 | 4.67 | 3.04 |
| | 112.00 | 73.65 | 33.13 | 16.92 | 9.93 | 6.43 | 4.46 |
| | 114.00 | 69.21 | 32.91 | 18.27 | 11.58 | 7.87 | 5.71 |
| | 116.00 | 64.46 | 32.69 | 19.54 | 13.04 | 9.33 | 7.01 |
| | 118.00 | 59.05 | 32.02 | 20.39 | 14.26 | 10.58 | 8.18 |
| | 120.00 | 52.39 | 30.32 | 20.33 | 14.77 | 11.28 | 8.92 |
| | 122.00 | 45.42 | 28.28 | 19.88 | 14.94 | 11.70 | 9.44 |
| | 124.00 | 39.94 | 27.02 | 19.91 | 15.44 | 12.38 | 10.17 |
| | 126.00 | 34.38 | 25.12 | 19.32 | 15.40 | 12.60 | 10.51 |
| | 128.00 | 30.43 | 23.88 | 19.10 | 15.64 | 13.03 | 11.03 |
| | 130.00 | 27.97 | 23.31 | 19.30 | 16.17 | 13.70 | 11.74 |
| | 132.00 | 24.64 | 21.67 | 18.54 | 15.87 | 13.66 | 11.85 |
| | 134.00 | 22.30 | 20.52 | 18.05 | 15.76 | 13.77 | 12.08 |
| | 136.00 | 20.78 | 19.81 | 17.86 | 15.85 | 14.03 | 12.43 |
| | 138.00 | 17.71 | 17.68 | 16.39 | 14.84 | 13.31 | 11.92 |
| | 140.00 | 17.43 | 17.73 | 16.68 | 15.28 | 13.84 | 12.49 |
| 80.00 | 110.00 | 87.65 | 56.40 | 37.94 | 27.64 | 21.39 | 17.29 |
| | 112.00 | 85.71 | 57.13 | 40.66 | 31.12 | 25.06 | 20.90 |
| | 114.00 | 82.96 | 56.73 | 42.10 | 33.39 | 27.65 | 23.60 |
| | 116.00 | 79.82 | 56.26 | 43.37 | 35.44 | 30.04 | 26.11 |
| | 118.00 | 75.94 | 55.33 | 44.08 | 36.94 | 31.91 | 28.15 |
| | 120.00 | 70.72 | 53.36 | 43.74 | 37.43 | 32.85 | 29.33 |
| | 122.00 | 64.52 | 50.94 | 42.95 | 37.46 | 33.34 | 30.09 |
| | 124.00 | 58.68 | 49.10 | 42.63 | 37.89 | 34.17 | 31.15 |
| | 126.00 | 52.12 | 46.51 | 41.58 | 37.61 | 34.33 | 31.57 |
| | 128.00 | 46.65 | 44.45 | 40.91 | 37.65 | 34.77 | 32.25 |
| | 130.00 | 42.59 | 43.01 | 40.68 | 38.03 | 35.50 | 33.19 |
| | 132.00 | 37.78 | 40.39 | 39.32 | 37.37 | 35.26 | 33.22 |
| | 134.00 | 34.11 | 38.26 | 38.25 | 36.93 | 35.21 | 33.42 |
| | 136.00 | 31.48 | 36.63 | 37.49 | 36.72 | 35.34 | 33.77 |
| | 138.00 | 27.34 | 33.41 | 35.21 | 35.18 | 34.17 | 32.91 |
| | 140.00 | 26.32 | 32.72 | 35.83 | 35.32 | 34.65 | 33.56 |
| 120.00 | 110.00 | 91.58 | 68.19 | 52.30 | 42.34 | 35.69 | 30.97 |
| | 112.00 | 90.21 | 68.73 | 54.74 | 45.79 | 39.64 | 35.13 |
| | 114.00 | 88.24 | 68.35 | 55.98 | 47.96 | 42.31 | 38.08 |
| | 116.00 | 85.93 | 67.98 | 57.84 | 49.87 | 44.69 | 41.71 |
| | 118.00 | 83.01 | 67.03 | 57.58 | 51.21 | 46.49 | 42.79 |
| | 120.00 | 78.92 | 65.29 | 57.21 | 51.61 | 47.38 | 43.95 |
| | 122.00 | 73.81 | 63.09 | 56.40 | 51.57 | 47.79 | 44.68 |
| | 124.00 | 68.61 | 61.31 | 56.00 | 51.89 | 48.54 | 45.70 |
| | 126.00 | 62.35 | 58.81 | 54.92 | 51.55 | 48.63 | 46.08 |
| | 128.00 | 56.59 | 56.68 | 54.36 | 51.50 | 48.99 | 46.70 |
| | 130.00 | 51.86 | 55.02 | 53.77 | 51.75 | 49.62 | 47.56 |
| | 132.00 | 46.33 | 52.22 | 52.32 | 51.02 | 49.33 | 47.55 |
| | 134.00 | 41.91 | 49.77 | 51.11 | 50.49 | 49.20 | 47.69 |
| | 136.00 | 38.56 | 47.74 | 50.16 | 50.16 | 49.25 | 47.98 |
| | 138.00 | 33.78 | 44.12 | 47.74 | 48.48 | 48.86 | 47.09 |
| | 140.00 | 32.22 | 42.93 | 47.28 | 48.53 | 48.41 | 47.66 |

Table E- 14--continued.

| D (min) | Temp | % Retention<br>Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| 160.00 | 110.00 | 93.61 | 75.01 | 61.45 | 52.44 | 46.34 | 41.68 |
| | 112.00 | 92.55 | 75.43 | 63.58 | 55.61 | 49.90 | 45.59 |
| | 114.00 | 91.02 | 75.10 | 64.63 | 57.55 | 52.39 | 48.42 |
| | 116.00 | 89.21 | 74.69 | 65.52 | 59.24 | 54.57 | 50.91 |
| | 118.00 | 86.87 | 73.93 | 65.96 | 60.42 | 56.20 | 52.83 |
| | 120.00 | 83.54 | 72.41 | 65.59 | 60.74 | 56.97 | 53.89 |
| | 122.00 | 79.26 | 70.49 | 66.85 | 60.68 | 57.34 | 54.55 |
| | 124.00 | 74.71 | 68.88 | 64.44 | 60.93 | 57.99 | 55.47 |
| | 126.00 | 69.00 | 66.60 | 63.43 | 60.59 | 58.06 | 55.79 |
| | 128.00 | 63.40 | 64.60 | 62.69 | 60.49 | 58.35 | 56.34 |
| | 130.00 | 58.46 | 62.94 | 62.26 | 60.67 | 58.88 | 57.10 |
| | 132.00 | 52.60 | 60.23 | 60.88 | 59.97 | 58.59 | 57.07 |
| | 134.00 | 47.72 | 57.75 | 59.69 | 59.43 | 58.43 | 57.17 |
| | 136.00 | 43.88 | 55.59 | 58.71 | 59.07 | 58.44 | 57.41 |
| | 138.00 | 38.67 | 51.89 | 56.37 | 57.49 | 57.31 | 56.58 |
| | 140.00 | 36.68 | 50.42 | 55.79 | 57.45 | 57.60 | 57.06 |
| 200.00 | 110.00 | 94.85 | 79.43 | 67.71 | 59.64 | 53.83 | 49.45 |
| | 112.00 | 93.99 | 79.78 | 69.57 | 62.58 | 57.32 | 53.32 |
| | 114.00 | 92.74 | 79.49 | 70.48 | 64.23 | 59.59 | 55.95 |
| | 116.00 | 91.25 | 79.12 | 71.24 | 65.73 | 61.56 | 58.23 |
| | 118.00 | 89.30 | 78.45 | 71.61 | 66.76 | 63.82 | 59.98 |
| | 120.00 | 86.50 | 77.13 | 71.27 | 67.83 | 63.70 | 60.94 |
| | 122.00 | 82.84 | 75.44 | 70.59 | 66.96 | 66.81 | 61.52 |
| | 124.00 | 78.66 | 73.99 | 70.21 | 67.16 | 64.58 | 62.34 |
| | 126.00 | 73.67 | 71.95 | 69.29 | 66.84 | 64.63 | 62.62 |
| | 128.00 | 68.38 | 70.10 | 68.59 | 66.73 | 66.87 | 63.11 |
| | 130.00 | 63.45 | 68.53 | 68.16 | 66.80 | 65.33 | 63.78 |
| | 132.00 | 57.49 | 63.97 | 66.89 | 66.21 | 65.85 | 63.74 |
| | 134.00 | 52.31 | 63.58 | 65.76 | 65.69 | 64.89 | 63.81 |
| | 136.00 | 48.13 | 61.42 | 66.81 | 65.34 | 66.88 | 64.01 |
| | 138.00 | 42.62 | 57.79 | 62.61 | 63.88 | 63.84 | 63.26 |
| | 140.00 | 40.28 | 56.18 | 61.99 | 63.80 | 64.07 | 63.68 |
| 240.00 | 110.00 | 95.69 | 82.53 | 72.25 | 66.99 | 59.67 | 55.59 |
| | 112.00 | 94.96 | 82.83 | 73.89 | 67.57 | 62.87 | 59.20 |
| | 114.00 | 93.91 | 82.56 | 74.69 | 69.13 | 64.94 | 61.62 |
| | 116.00 | 92.66 | 82.24 | 75.35 | 70.46 | 66.72 | 63.70 |
| | 118.00 | 90.98 | 81.64 | 75.66 | 71.37 | 68.03 | 65.29 |
| | 120.00 | 88.56 | 80.47 | 75.35 | 71.61 | 68.63 | 66.15 |
| | 122.00 | 85.37 | 78.97 | 74.73 | 71.53 | 68.91 | 66.68 |
| | 124.00 | 81.82 | 77.67 | 74.38 | 71.70 | 69.42 | 67.41 |
| | 126.00 | 77.13 | 75.83 | 73.54 | 71.40 | 69.44 | 67.66 |
| | 128.00 | 72.17 | 74.13 | 72.90 | 71.29 | 69.66 | 68.09 |
| | 130.00 | 67.36 | 72.67 | 72.49 | 71.39 | 70.06 | 68.69 |
| | 132.00 | 61.43 | 70.28 | 71.31 | 70.79 | 69.79 | 68.64 |
| | 134.00 | 56.09 | 68.01 | 70.26 | 70.31 | 69.64 | 68.70 |
| | 136.00 | 51.66 | 65.92 | 69.36 | 69.96 | 69.61 | 68.08 |
| | 138.00 | 45.93 | 62.42 | 67.31 | 68.62 | 68.67 | 68.18 |
| | 140.00 | 43.31 | 62.75 | 66.69 | 68.52 | 68.86 | 68.55 |

Table E 15 Simulated quality retention of foods with thermal diffusivity $1.6 \times 10^{-7}$ $m^2/s$ after thermal processing in the conically shaped container #3 h = 300 w/m²K

|  |  | % Retention |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 40.00 | 110.00 | 77.57 | 33.74 | 16.07 | 8.91 | 5.53 | 3.73 |
|  | 112.00 | 74.72 | 35.25 | 18.86 | 11.53 | 7.74 | 5.54 |
|  | 114.00 | 70.87 | 35.57 | 20.72 | 13.59 | 9.63 | 7.21 |
|  | 116.00 | 66.00 | 35.03 | 21.83 | 15.10 | 11.15 | 8.63 |
|  | 118.00 | 60.89 | 33.77 | 22.26 | 16.87 | 12.26 | 9.72 |
|  | 120.00 | 55.34 | 33.69 | 23.53 | 17.69 | 13.92 | 11.30 |
|  | 122.00 | 49.12 | 32.10 | 23.48 | 18.23 | 14.68 | 12.14 |
|  | 124.00 | 42.21 | 29.81 | 22.75 | 18.18 | 14.95 | 12.57 |
|  | 126.00 | 36.94 | 28.22 | 22.45 | 18.43 | 15.46 | 13.18 |
|  | 128.00 | 33.37 | 27.37 | 22.62 | 19.03 | 16.24 | 14.04 |
|  | 130.00 | 29.00 | 25.37 | 21.73 | 18.69 | 16.21 | 14.17 |
|  | 132.00 | 25.88 | 23.92 | 21.15 | 18.59 | 16.36 | 14.47 |
|  | 134.00 | 23.82 | 23.01 | 20.51 | 18.72 | 16.70 | 14.92 |
|  | 136.00 | 20.11 | 21.50 | 19.24 | 17.59 | 15.94 | 14.41 |
|  | 138.00 | 19.65 | 20.40 | 19.57 | 18.14 | 16.60 | 15.12 |
|  | 140.00 | 17.23 | 18.72 | 18.34 | 17.30 | 16.04 | 14.77 |
| 80.00 | 110.00 | 88.04 | 57.86 | 39.82 | 29.62 | 23.34 | 19.17 |
|  | 112.00 | 86.36 | 59.02 | 43.04 | 33.63 | 27.56 | 23.35 |
|  | 114.00 | 84.01 | 59.13 | 45.00 | 36.43 | 30.70 | 26.59 |
|  | 116.00 | 80.87 | 58.45 | 46.03 | 38.30 | 32.97 | 29.25 |
|  | 118.00 | 76.78 | 57.07 | 46.28 | 39.39 | 34.50 | 30.79 |
|  | 120.00 | 73.84 | 56.63 | 47.38 | 41.21 | 36.67 | 33.14 |
|  | 122.00 | 67.64 | 54.77 | 47.06 | 41.67 | 37.57 | 34.29 |
|  | 124.00 | 61.89 | 52.15 | 46.00 | 41.43 | 37.79 | 34.81 |
|  | 126.00 | 55.04 | 50.01 | 45.35 | 41.51 | 38.31 | 35.58 |
|  | 128.00 | 50.07 | 48.47 | 45.14 | 41.97 | 39.14 | 36.63 |
|  | 130.00 | 44.21 | 45.69 | 43.77 | 41.35 | 38.95 | 36.71 |
|  | 132.00 | 39.59 | 43.37 | 42.71 | 40.96 | 38.97 | 36.99 |
|  | 134.00 | 36.18 | 41.55 | 41.97 | 40.83 | 39.21 | 37.46 |
|  | 136.00 | 31.21 | 37.99 | 39.59 | 39.21 | 38.08 | 36.67 |
|  | 138.00 | 29.81 | 37.16 | 39.48 | 39.56 | 38.69 | 37.48 |
|  | 140.00 | 26.45 | 34.40 | 37.52 | 38.23 | 37.80 | 36.87 |
| 120.00 | 110.00 | 91.85 | 69.38 | 54.04 | 44.35 | 37.84 | 33.28 |
|  | 112.00 | 90.67 | 70.27 | 56.89 | 48.25 | 42.26 | 37.85 |
|  | 114.00 | 88.99 | 70.31 | 58.56 | 50.87 | 45.39 | 41.26 |
|  | 116.00 | 86.71 | 69.70 | 59.48 | 52.56 | 47.59 | 43.75 |
|  | 118.00 | 83.66 | 68.51 | 59.57 | 53.52 | 49.01 | 45.47 |
|  | 120.00 | 80.74 | 68.04 | 60.43 | 55.11 | 51.03 | 47.73 |
|  | 122.00 | 76.38 | 66.35 | 60.07 | 55.47 | 51.82 | 48.81 |
|  | 124.00 | 70.77 | 64.03 | 59.06 | 55.19 | 51.99 | 49.27 |
|  | 126.00 | 65.13 | 62.01 | 58.37 | 55.20 | 52.42 | 49.97 |
|  | 128.00 | 59.99 | 60.41 | 58.08 | 55.53 | 53.13 | 50.92 |
|  | 130.00 | 53.74 | 57.67 | 56.70 | 54.88 | 52.90 | 50.96 |
|  | 132.00 | 48.42 | 55.22 | 55.58 | 54.44 | 52.86 | 51.18 |
|  | 134.00 | 44.26 | 53.14 | 54.72 | 54.22 | 53.02 | 51.58 |
|  | 136.00 | 38.59 | 49.37 | 52.35 | 52.63 | 51.91 | 50.79 |
|  | 138.00 | 36.52 | 48.69 | 51.99 | 52.00 | 52.40 | 51.49 |
|  | 140.00 | 32.58 | 44.94 | 49.93 | 51.45 | 51.50 | 50.88 |

Table E- 15—continued.

| D (min) | Temp | % Retention<br>Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| 160.00 | 110.00 | 93.82 | 75.99 | 62.99 | 54.31 | 48.22 | 43.71 |
| | 112.00 | 92.91 | 76.71 | 65.45 | 57.85 | 52.37 | 48.22 |
| | 114.00 | 91.60 | 76.72 | 66.88 | 60.17 | 55.25 | 51.44 |
| | 116.00 | 89.82 | 76.20 | 67.57 | 61.65 | 57.23 | 53.74 |
| | 118.00 | 87.40 | 75.18 | 67.89 | 62.47 | 58.50 | 55.31 |
| | 120.00 | 85.03 | 74.75 | 68.30 | 63.84 | 60.28 | 57.35 |
| | 122.00 | 81.41 | 73.31 | 68.05 | 64.13 | 60.97 | 58.31 |
| | 124.00 | 76.82 | 71.25 | 67.14 | 63.86 | 61.10 | 58.71 |
| | 126.00 | 71.55 | 69.43 | 66.49 | 63.83 | 61.66 | 59.32 |
| | 128.00 | 66.64 | 67.93 | 66.18 | 64.09 | 62.06 | 60.15 |
| | 130.00 | 60.43 | 65.40 | 64.91 | 63.48 | 61.64 | 60.17 |
| | 132.00 | 54.84 | 63.05 | 63.85 | 63.05 | 61.78 | 60.36 |
| | 134.00 | 50.22 | 60.98 | 63.00 | 62.81 | 61.88 | 60.69 |
| | 136.00 | 44.14 | 57.30 | 60.79 | 61.35 | 60.87 | 59.97 |
| | 138.00 | 41.58 | 55.83 | 60.35 | 61.44 | 61.27 | 60.56 |
| | 140.00 | 37.23 | 52.57 | 58.36 | 60.17 | 60.43 | 60.00 |
| 200.00 | 110.00 | 95.02 | 80.27 | 69.07 | 61.35 | 55.77 | 51.56 |
| | 112.00 | 94.28 | 80.87 | 71.22 | 64.51 | 59.58 | 55.77 |
| | 114.00 | 93.22 | 80.87 | 72.44 | 66.57 | 62.18 | 58.73 |
| | 116.00 | 91.75 | 80.41 | 73.04 | 67.87 | 63.95 | 60.82 |
| | 118.00 | 89.75 | 79.53 | 73.12 | 68.58 | 65.08 | 62.23 |
| | 120.00 | 87.76 | 79.14 | 73.71 | 69.77 | 66.65 | 64.06 |
| | 122.00 | 84.08 | 77.88 | 73.39 | 70.01 | 67.25 | 64.91 |
| | 124.00 | 80.52 | 76.08 | 72.58 | 69.76 | 67.36 | 65.26 |
| | 126.00 | 75.98 | 74.45 | 71.99 | 69.72 | 67.66 | 65.79 |
| | 128.00 | 71.40 | 73.08 | 71.07 | 69.92 | 68.18 | 66.52 |
| | 130.00 | 65.43 | 70.77 | 70.54 | 69.37 | 67.97 | 66.53 |
| | 132.00 | 59.78 | 68.59 | 69.56 | 66.97 | 67.00 | 66.68 |
| | 134.00 | 54.91 | 66.60 | 68.78 | 68.73 | 67.98 | 66.97 |
| | 136.00 | 48.57 | 63.11 | 66.74 | 67.41 | 67.07 | 66.32 |
| | 138.00 | 45.64 | 61.58 | 66.27 | 67.45 | 67.40 | 66.83 |
| | 140.00 | 40.98 | 58.36 | 64.41 | 66.29 | 66.64 | 66.32 |
| 240.00 | 110.00 | 95.83 | 83.26 | 73.45 | 66.54 | 61.46 | 57.57 |
| | 112.00 | 95.21 | 83.77 | 75.35 | 69.39 | 64.98 | 61.46 |
| | 114.00 | 94.33 | 83.76 | 76.42 | 71.22 | 67.29 | 64.16 |
| | 116.00 | 93.07 | 83.38 | 76.94 | 72.37 | 68.88 | 66.06 |
| | 118.00 | 91.36 | 82.59 | 77.00 | 73.00 | 69.89 | 67.33 |
| | 120.00 | 89.85 | 82.23 | 77.51 | 74.05 | 71.29 | 68.97 |
| | 122.00 | 86.98 | 81.12 | 77.22 | 74.25 | 71.82 | 69.73 |
| | 124.00 | 83.32 | 79.52 | 76.49 | 74.02 | 71.80 | 70.04 |
| | 126.00 | 79.23 | 78.06 | 75.95 | 73.98 | 72.17 | 70.51 |
| | 128.00 | 74.97 | 76.81 | 75.85 | 74.14 | 72.62 | 71.18 |
| | 130.00 | 69.30 | 74.71 | 74.83 | 73.64 | 72.43 | 71.16 |
| | 132.00 | 63.73 | 72.69 | 73.73 | 73.27 | 72.36 | 71.29 |
| | 134.00 | 58.73 | 70.82 | 72.99 | 73.04 | 72.42 | 71.54 |
| | 136.00 | 52.24 | 67.55 | 71.14 | 71.84 | 71.59 | 70.95 |
| | 138.00 | 49.82 | 66.03 | 70.67 | 71.86 | 71.88 | 71.41 |
| | 140.00 | 44.13 | 62.90 | 66.94 | 70.80 | 71.18 | 70.94 |

Table E-10 Simulated quality retention of food with thermal diffusivity = $1.2 \times 10^{-7}$ $m^2/s$ after thermal processing in a conically shaped container # 3. Infinite h

|  |  | % Retention |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| **D (min)** | **Temp** | **Z = 10°C** | **Z = 20°C** | **Z = 30°C** | **Z = 40°C** | **Z = 50°C** | **Z = 60°C** |
| 40.00 | 110.00 | 74.76 | 29.19 | 12.62 | 6.45 | 3.73 | 2.36 |
|  | 112.00 | 70.58 | 29.54 | 14.33 | 8.09 | 5.07 | 3.42 |
|  | 114.00 | 65.85 | 29.48 | 15.66 | 9.54 | 6.34 | 4.49 |
|  | 116.00 | 59.82 | 28.65 | 16.48 | 10.66 | 7.43 | 5.46 |
|  | 118.00 | 53.38 | 27.58 | 16.89 | 11.47 | 8.31 | 6.29 |
|  | 120.00 | 47.25 | 26.48 | 17.27 | 12.25 | 9.16 | 7.11 |
|  | 122.00 | 40.18 | 24.30 | 16.85 | 12.22 | 9.38 | 7.43 |
|  | 124.00 | 34.74 | 22.85 | 16.43 | 12.47 | 9.81 | 7.92 |
|  | 126.00 | 29.47 | 20.92 | 15.70 | 12.80 | 10.30 | 8.30 |
|  | 128.00 | 26.58 | 20.00 | 15.18 | 13.09 | 10.72 | 8.93 |
|  | 130.00 | 23.34 | 18.83 | 15.24 | 12.53 | 10.44 | 9.10 |
|  | 132.00 | 20.30 | 17.24 | 14.42 | 12.12 | 10.28 | 9.30 |
|  | 134.00 | 19.58 | 16.70 | 13.68 | 12.20 | 11.01 | 9.30 |
|  | 136.00 | 16.62 | 15.30 | 13.49 | 11.77 | 10.27 | 8.99 |
|  | 138.00 | 15.72 | 14.87 | 13.37 | 11.84 | 10.45 | 9.23 |
|  | 140.00 | 15.30 | 14.77 | 13.48 | 12.09 | 10.77 | 9.59 |
| 80.00 | 110.00 | 86.38 | 53.58 | 35.04 | 25.00 | 19.03 | 15.17 |
|  | 112.00 | 83.82 | 53.67 | 37.18 | 27.89 | 22.13 | 18.23 |
|  | 114.00 | 80.61 | 53.23 | 38.65 | 30.16 | 24.66 | 20.80 |
|  | 116.00 | 76.58 | 52.13 | 39.39 | 31.73 | 26.58 | 23.87 |
|  | 118.00 | 71.45 | 50.53 | 39.56 | 32.74 | 28.00 | 24.48 |
|  | 120.00 | 65.93 | 48.92 | 39.65 | 33.61 | 29.26 | 25.93 |
|  | 122.00 | 58.87 | 46.84 | 38.50 | 33.33 | 29.46 | 26.42 |
|  | 124.00 | 52.43 | 43.73 | 37.78 | 33.39 | 29.96 | 27.16 |
|  | 126.00 | 45.70 | 40.79 | 36.39 | 32.81 | 29.84 | 27.32 |
|  | 128.00 | 41.89 | 39.80 | 38.60 | 33.61 | 30.95 | 28.61 |
|  | 130.00 | 36.18 | 36.61 | 34.74 | 32.51 | 30.32 | 26.29 |
|  | 132.00 | 31.67 | 33.69 | 33.14 | 31.59 | 29.83 | 28.09 |
|  | 134.00 | 30.12 | 33.30 | 33.28 | 32.17 | 30.68 | 29.10 |
|  | 136.00 | 25.73 | 29.90 | 30.81 | 30.35 | 29.32 | 28.06 |
|  | 138.00 | 23.99 | 28.62 | 30.89 | 30.07 | 29.33 | 28.27 |
|  | 140.00 | 22.92 | 27.00 | 29.68 | 30.81 | 29.53 | 28.85 |
| 128.00 | 110.00 | 90.68 | 65.84 | 49.55 | 39.55 | 32.97 | 28.35 |
|  | 112.00 | 88.85 | 65.85 | 51.48 | 42.50 | 36.40 | 32.00 |
|  | 114.00 | 86.51 | 65.39 | 52.76 | 44.72 | 39.12 | 34.96 |
|  | 116.00 | 83.42 | 64.35 | 53.34 | 46.20 | 41.10 | 37.21 |
|  | 118.00 | 79.48 | 62.85 | 53.38 | 47.10 | 42.58 | 38.90 |
|  | 120.00 | 74.89 | 61.27 | 53.33 | 47.86 | 43.72 | 40.48 |
|  | 122.00 | 68.70 | 58.52 | 52.12 | 47.50 | 43.86 | 40.86 |
|  | 124.00 | 62.53 | 56.16 | 51.28 | 47.45 | 44.28 | 41.58 |
|  | 126.00 | 55.64 | 53.13 | 49.79 | 46.77 | 44.08 | 41.70 |
|  | 128.00 | 51.11 | 51.77 | 49.75 | 47.40 | 45.10 | 42.95 |
|  | 130.00 | 44.69 | 48.31 | 47.74 | 46.19 | 44.38 | 42.56 |
|  | 132.00 | 39.33 | 45.18 | 45.92 | 45.13 | 43.80 | 42.29 |
|  | 134.00 | 36.97 | 44.05 | 45.75 | 45.52 | 44.53 | 43.24 |
|  | 136.00 | 31.90 | 40.17 | 43.81 | 43.55 | 43.08 | 42.12 |
|  | 138.00 | 29.58 | 38.35 | 41.97 | 43.86 | 42.95 | 42.25 |
|  | 140.00 | 28.01 | 37.02 | 41.22 | 42.79 | 43.01 | 42.55 |

Table E 16 —continued

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 30°C |
| 180.00 | 110.00 | 92.92 | 73.04 | 58.98 | 49.88 | 43.45 | 38.80 |
| | 112.00 | 91.50 | 73.02 | 60.68 | 52.54 | 46.79 | 42.48 |
| | 114.00 | 89.66 | 72.59 | 61.77 | 54.57 | 49.37 | 45.39 |
| | 116.00 | 87.20 | 71.67 | 62.24 | 55.89 | 51.21 | 47.56 |
| | 118.00 | 83.59 | 70.32 | 62.23 | 56.68 | 52.49 | 49.15 |
| | 120.00 | 80.14 | 68.89 | 82.11 | 57.32 | 53.59 | 50.54 |
| | 122.00 | 74.76 | 66.41 | 60.98 | 56.94 | 53.68 | 50.96 |
| | 124.00 | 69.08 | 66.19 | 80.14 | 56.85 | 54.05 | 51.81 |
| | 126.00 | 82.45 | 61.32 | 58.71 | 56.17 | 53.83 | 51.69 |
| | 128.00 | 57.65 | 59.86 | 58.55 | 56.68 | 54.72 | 52.83 |
| | 130.00 | 50.96 | 56.44 | 56.68 | 55.58 | 54.02 | 52.44 |
| | 132.00 | 45.12 | 53.24 | 54.79 | 54.45 | 53.43 | 52.16 |
| | 134.00 | 42.17 | 51.84 | 54.46 | 54.71 | 54.05 | 53.00 |
| | 136.00 | 36.61 | 47.79 | 51.74 | 52.79 | 52.63 | 51.92 |
| | 138.00 | 33.85 | 45.67 | 50.55 | 52.22 | 52.45 | 52.00 |
| | 140.00 | 31.98 | 43.99 | 49.62 | 51.85 | 52.44 | 52.23 |
| 200.00 | 110.00 | 94.29 | 77.75 | 65.51 | 57.27 | 51.30 | 46.87 |
| | 112.00 | 93.13 | 77.72 | 87.00 | 59.71 | 54.42 | 50.38 |
| | 114.00 | 91.62 | 77.33 | 67.95 | 61.53 | 56.80 | 53.11 |
| | 116.00 | 89.58 | 76.51 | 68.33 | 62.71 | 58.48 | 55.13 |
| | 118.00 | 86.88 | 75.32 | 66.30 | 63.39 | 59.63 | 56.59 |
| | 120.00 | 83.57 | 74.03 | 68.18 | 83.95 | 60.82 | 57.86 |
| | 122.00 | 78.86 | 71.80 | 67.12 | 63.58 | 60.69 | 58.23 |
| | 124.00 | 73.69 | 69.77 | 66.33 | 63.47 | 61.00 | 58.81 |
| | 126.00 | 87.43 | 87.11 | 65.00 | 62.83 | 60.78 | 58.87 |
| | 128.00 | 62.59 | 65.66 | 64.79 | 63.24 | 61.56 | 59.89 |
| | 130.00 | 55.83 | 62.40 | 62.95 | 62.14 | 60.90 | 59.52 |
| | 132.00 | 49.74 | 59.26 | 61.23 | 61.14 | 60.33 | 59.25 |
| | 134.00 | 44.60 | 96.00 | 60.82 | 61.33 | 60.66 | 60.00 |
| | 136.00 | 40.45 | 53.89 | 58.21 | 59.51 | 59.54 | 54.99 |
| | 138.00 | 37.32 | 51.40 | 56.98 | 58.93 | 59.34 | 59.04 |
| | 140.00 | 35.06 | 49.51 | 55.97 | 58.51 | 59.29 | 59.23 |
| 240.00 | 110.00 | 95.21 | 81.06 | 70.27 | 62.77 | 57.32 | 53.16 |
| | 112.00 | 94.24 | 81.03 | 71.59 | 65.04 | 60.21 | 56.46 |
| | 114.00 | 92.95 | 86.68 | 72.42 | 66.68 | 62.39 | 59.00 |
| | 116.00 | 91.21 | 79.95 | 72.75 | 87.73 | 63.91 | 60.85 |
| | 118.00 | 88.88 | 78.88 | 72.70 | 66.33 | 64.95 | 62.19 |
| | 120.00 | 86.00 | 77.72 | 72.57 | 66.82 | 65.84 | 65.34 |
| | 122.00 | 81.81 | 75.71 | 71.81 | 68.48 | 65.89 | 83.67 |
| | 124.00 | 77.10 | 73.85 | 70.87 | 66.35 | 66.16 | 66.20 |
| | 126.00 | 71.24 | 71.41 | 69.64 | 67.76 | 65.94 | 66.24 |
| | 128.00 | 66.47 | 78.01 | 89.41 | 68.11 | 86.64 | 65.16 |
| | 130.00 | 59.77 | 66.94 | 67.71 | 67.08 | 66.02 | 64.81 |
| | 132.00 | 53.55 | 63.93 | 66.08 | 66.15 | 65.49 | 64.55 |
| | 134.00 | 48.40 | 62.34 | 85.65 | 66.28 | 85.95 | 65.22 |
| | 136.00 | 43.69 | 58.38 | 63.18 | 64.60 | 64.73 | 64.28 |
| | 138.00 | 40.25 | 56.02 | 61.96 | 66.02 | 66.52 | 66.32 |
| | 140.00 | 37.73 | 54.01 | 60.93 | 83.59 | 64.45 | 64.47 |

Table E-17 Simulated quality retention of food with thermal diffusivity = 1.4x 10$^{-7}$ m$^2$/s after thermal processing in a conically shaped container 0.3 Infinite h

|  |  | % Retention |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 48.00 | 110.00 | 76.14 | 31.88 | 14.60 | 8.05 | 4.92 | 3.27 |
|  | 112.00 | 72.20 | 32.33 | 16.75 | 10.01 | 6.59 | 4.65 |
|  | 114.00 | 67.39 | 32.12 | 18.16 | 11.65 | 8.12 | 6.00 |
|  | 116.00 | 62.32 | 31.97 | 19.54 | 13.32 | 9.71 | 7.43 |
|  | 118.00 | 55.60 | 30.40 | 19.71 | 14.04 | 10.60 | 8.33 |
|  | 120.00 | 48.76 | 28.77 | 19.71 | 14.60 | 11.35 | 9.12 |
|  | 122.00 | 43.52 | 28.12 | 20.34 | 15.64 | 12.49 | 10.25 |
|  | 124.00 | 36.86 | 25.77 | 19.48 | 15.43 | 12.59 | 10.50 |
|  | 126.00 | 31.83 | 24.89 | 19.81 | 15.49 | 12.80 | 10.92 |
|  | 128.00 | 28.45 | 23.10 | 18.96 | 15.84 | 13.43 | 11.54 |
|  | 130.00 | 24.52 | 21.18 | 18.01 | 15.41 | 13.30 | 11.58 |
|  | 132.00 | 21.71 | 19.77 | 17.36 | 15.17 | 13.30 | 11.73 |
|  | 134.00 | 19.83 | 18.83 | 16.99 | 15.14 | 13.46 | 12.00 |
|  | 136.00 | 18.72 | 18.35 | 16.92 | 15.32 | 13.77 | 12.38 |
|  | 138.00 | 16.11 | 16.47 | 15.60 | 14.39 | 13.13 | 11.93 |
|  | 140.00 | 16.15 | 16.73 | 16.03 | 14.94 | 13.74 | 12.58 |
| 80.00 | 110.00 | 87.20 | 56.11 | 38.08 | 28.05 | 21.94 | 17.90 |
|  | 112.00 | 84.83 | 56.33 | 40.38 | 31.19 | 25.34 | 21.32 |
|  | 114.00 | 81.77 | 55.89 | 41.86 | 33.55 | 28.06 | 24.15 |
|  | 116.00 | 78.28 | 55.42 | 43.21 | 35.72 | 30.59 | 26.82 |
|  | 118.00 | 73.27 | 53.58 | 43.13 | 36.52 | 31.85 | 28.33 |
|  | 120.00 | 67.49 | 51.53 | 42.60 | 37.05 | 32.85 | 29.59 |
|  | 122.00 | 62.14 | 50.27 | 43.13 | 38.13 | 34.32 | 31.27 |
|  | 124.00 | 54.94 | 47.25 | 41.77 | 37.63 | 34.30 | 31.55 |
|  | 126.00 | 48.59 | 44.73 | 40.79 | 37.43 | 34.56 | 32.08 |
|  | 128.00 | 43.55 | 42.81 | 40.22 | 37.57 | 35.10 | 32.86 |
|  | 130.00 | 37.96 | 39.85 | 38.61 | 36.71 | 34.71 | 32.78 |
|  | 132.00 | 33.64 | 37.38 | 37.30 | 36.08 | 34.50 | 32.85 |
|  | 134.00 | 30.49 | 35.43 | 36.30 | 35.68 | 34.46 | 33.08 |
|  | 136.00 | 28.34 | 34.02 | 35.64 | 35.53 | 34.66 | 33.46 |
|  | 138.00 | 24.74 | 31.06 | 33.47 | 33.97 | 33.54 | 32.65 |
|  | 140.00 | 24.12 | 30.60 | 33.43 | 34.28 | 34.10 | 33.39 |
| 120.00 | 110.00 | 91.26 | 67.94 | 52.41 | 42.74 | 36.28 | 31.69 |
|  | 112.00 | 89.57 | 68.06 | 54.46 | 45.84 | 39.92 | 35.59 |
|  | 114.00 | 87.37 | 67.63 | 55.73 | 48.08 | 42.70 | 38.66 |
|  | 116.00 | 84.77 | 67.14 | 56.84 | 50.09 | 45.20 | 41.44 |
|  | 118.00 | 80.93 | 65.50 | 56.68 | 50.78 | 46.40 | 42.96 |
|  | 120.00 | 76.26 | 63.63 | 56.28 | 51.20 | 47.32 | 44.18 |
|  | 122.00 | 71.58 | 62.33 | 56.44 | 52.12 | 48.68 | 45.81 |
|  | 124.00 | 64.97 | 59.47 | 55.08 | 51.56 | 48.60 | 46.05 |
|  | 126.00 | 58.58 | 56.93 | 54.02 | 51.27 | 48.78 | 46.52 |
|  | 128.00 | 53.01 | 54.82 | 53.31 | 51.29 | 49.22 | 47.24 |
|  | 130.00 | 46.76 | 51.67 | 51.61 | 50.37 | 48.77 | 47.10 |
|  | 132.00 | 41.61 | 48.87 | 50.14 | 49.63 | 48.45 | 47.11 |
|  | 134.00 | 37.63 | 46.49 | 48.93 | 49.10 | 48.38 | 47.28 |
|  | 136.00 | 34.77 | 44.59 | 48.01 | 48.79 | 48.44 | 47.58 |
|  | 138.00 | 30.56 | 41.16 | 45.62 | 47.13 | 47.26 | 46.74 |
|  | 140.00 | 29.43 | 40.19 | 45.25 | 47.23 | 47.68 | 47.37 |

Table E- 17 --continued

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| D (min) | Temp | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 160.00 | 110.00 | 93.36 | 74.79 | 61.54 | 52.80 | 46.70 | 42.20 |
| | 112.00 | 92.08 | 74.87 | 63.31 | 55.64 | 50.16 | 46.03 |
| | 114.00 | 90.34 | 74.48 | 64.40 | 57.65 | 52.75 | 48.97 |
| | 116.00 | 88.28 | 74.03 | 65.33 | 59.42 | 55.03 | 51.58 |
| | 118.00 | 85.18 | 72.61 | 65.15 | 60.01 | 56.11 | 52.97 |
| | 120.00 | 81.31 | 70.96 | 64.75 | 60.35 | 56.92 | 54.09 |
| | 122.00 | 77.26 | 69.75 | 64.83 | 61.13 | 58.12 | 55.57 |
| | 124.00 | 71.36 | 67.18 | 63.57 | 60.59 | 58.02 | 55.76 |
| | 126.00 | 65.29 | 64.81 | 62.56 | 60.29 | 58.15 | 56.18 |
| | 128.00 | 59.64 | 62.74 | 61.84 | 60.24 | 58.51 | 56.80 |
| | 130.00 | 53.17 | 59.69 | 60.22 | 59.36 | 58.07 | 56.65 |
| | 132.00 | 47.57 | 56.80 | 58.77 | 58.63 | 57.77 | 56.64 |
| | 134.00 | 43.05 | 54.35 | 57.53 | 58.08 | 57.63 | 56.76 |
| | 136.00 | 39.65 | 52.23 | 56.53 | 57.71 | 57.64 | 57.00 |
| | 138.00 | 34.99 | 48.63 | 54.16 | 56.11 | 56.52 | 56.20 |
| | 140.00 | 33.46 | 47.32 | 53.62 | 56.10 | 56.84 | 56.73 |
| 200.00 | 110.00 | 94.65 | 79.24 | 67.79 | 59.97 | 54.36 | 50.12 |
| | 112.00 | 93.59 | 79.30 | 69.33 | 62.52 | 57.55 | 53.73 |
| | 114.00 | 92.18 | 78.95 | 70.27 | 64.31 | 59.90 | 56.45 |
| | 116.00 | 90.47 | 78.55 | 71.08 | 65.88 | 61.97 | 58.84 |
| | 118.00 | 87.89 | 77.38 | 70.88 | 66.38 | 62.92 | 60.10 |
| | 120.00 | 84.60 | 75.85 | 70.51 | 66.67 | 63.64 | 61.11 |
| | 122.00 | 81.08 | 74.75 | 70.56 | 67.33 | 64.69 | 62.43 |
| | 124.00 | 75.78 | 72.45 | 69.41 | 66.84 | 64.60 | 62.80 |
| | 126.00 | 70.12 | 70.27 | 68.47 | 66.54 | 64.69 | 62.96 |
| | 128.00 | 64.60 | 68.33 | 67.77 | 66.47 | 64.99 | 63.50 |
| | 130.00 | 58.10 | 65.46 | 66.27 | 65.65 | 64.58 | 63.36 |
| | 132.00 | 52.28 | 62.72 | 64.91 | 64.97 | 64.29 | 63.33 |
| | 134.00 | 47.40 | 60.22 | 63.70 | 64.42 | 64.14 | 63.42 |
| | 136.00 | 43.68 | 58.02 | 62.70 | 64.05 | 64.12 | 63.62 |
| | 138.00 | 38.59 | 54.39 | 60.43 | 62.55 | 63.08 | 62.88 |
| | 140.00 | 36.74 | 52.88 | 59.81 | 62.48 | 63.33 | 63.34 |
| 240.00 | 110.00 | 95.52 | 82.36 | 72.31 | 65.29 | 60.15 | 56.23 |
| | 112.00 | 94.62 | 82.41 | 73.67 | 67.59 | 63.08 | 59.57 |
| | 114.00 | 93.43 | 82.10 | 74.49 | 69.19 | 65.22 | 62.08 |
| | 116.00 | 91.98 | 81.73 | 75.18 | 70.59 | 67.08 | 64.25 |
| | 118.00 | 89.76 | 80.63 | 75.81 | 71.03 | 67.94 | 65.40 |
| | 120.00 | 86.90 | 79.33 | 74.67 | 71.27 | 68.57 | 66.30 |
| | 122.00 | 83.77 | 78.34 | 74.67 | 71.85 | 69.51 | 67.49 |
| | 124.00 | 79.02 | 76.27 | 73.64 | 71.40 | 69.42 | 67.64 |
| | 126.00 | 73.77 | 74.28 | 72.78 | 71.12 | 69.49 | 67.95 |
| | 128.00 | 68.45 | 72.47 | 72.13 | 71.03 | 69.75 | 68.44 |
| | 130.00 | 62.05 | 69.80 | 70.75 | 70.28 | 69.37 | 68.30 |
| | 132.00 | 56.12 | 67.20 | 69.47 | 69.64 | 69.09 | 68.26 |
| | 134.00 | 51.82 | 64.76 | 68.33 | 69.13 | 68.94 | 68.34 |
| | 136.00 | 46.93 | 62.56 | 67.36 | 68.75 | 68.90 | 68.51 |
| | 138.00 | 41.64 | 58.98 | 65.22 | 67.37 | 67.95 | 67.83 |
| | 140.00 | 39.49 | 57.35 | 64.56 | 67.26 | 68.16 | 68.23 |

Table E.19 Simulated quality retention of foods with thermal diffusivity 1.6 x $10^{-7}$ $m^2$/s after thermal processing in a conically shaped container # 3. Infinite h

| D (min) | Temp(°C) | % Retention<br>Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| 40.00 | 110.00 | 76.87 | 33.71 | 16.42 | 9.32 | 5.92 | 4.07 |
| | 112.00 | 73.46 | 34.85 | 18.87 | 11.77 | 8.06 | 5.87 |
| | 114.00 | 69.25 | 34.99 | 20.83 | 13.96 | 10.10 | 7.70 |
| | 116.00 | 64.05 | 34.53 | 22.06 | 15.61 | 11.78 | 9.28 |
| | 118.00 | 57.94 | 33.40 | 22.64 | 16.74 | 13.65 | 10.54 |
| | 120.00 | 51.74 | 32.24 | 23.07 | 17.72 | 14.21 | 11.73 |
| | 122.00 | 45.46 | 30.78 | 23.11 | 18.35 | 15.07 | 12.68 |
| | 124.00 | 39.06 | 28.66 | 22.51 | 18.40 | 15.43 | 13.19 |
| | 126.00 | 34.35 | 27.31 | 22.36 | 18.78 | 16.05 | 13.92 |
| | 128.00 | 28.16 | 24.85 | 21.24 | 18.28 | 15.90 | 13.96 |
| | 130.00 | 25.39 | 23.17 | 20.45 | 18.01 | 15.83 | 14.17 |
| | 132.00 | 22.83 | 21.96 | 19.99 | 17.98 | 16.14 | 14.52 |
| | 134.00 | 21.28 | 21.28 | 19.89 | 18.21 | 16.56 | 15.84 |
| | 136.00 | 18.13 | 18.06 | 18.36 | 17.10 | 15.84 | 14.56 |
| | 138.00 | 18.06 | 18.30 | 18.86 | 17.83 | 16.81 | 15.37 |
| | 140.00 | 16.09 | 17.80 | 17.79 | 17.10 | 16.13 | 15.87 |
| 80.00 | 110.00 | 87.68 | 57.78 | 48.20 | 30.27 | 24.13 | 20.83 |
| | 112.00 | 85.59 | 58.44 | 42.98 | 33.94 | 28.09 | 24.02 |
| | 114.00 | 82.96 | 58.51 | 45.01 | 36.83 | 31.39 | 27.45 |
| | 116.00 | 79.50 | 57.83 | 46.23 | 38.86 | 33.82 | 30.08 |
| | 118.00 | 75.06 | 58.48 | 48.50 | 40.05 | 35.51 | 32.81 |
| | 120.00 | 69.87 | 54.99 | 46.66 | 41.09 | 36.85 | 33.70 |
| | 122.00 | 64.12 | 53.09 | 46.38 | 41.62 | 37.94 | 34.96 |
| | 124.00 | 57.36 | 50.47 | 45.37 | 41.45 | 38.25 | 35.57 |
| | 126.00 | 51.44 | 48.40 | 44.80 | 41.63 | 38.87 | 36.45 |
| | 128.00 | 44.78 | 45.22 | 43.15 | 40.79 | 38.51 | 36.39 |
| | 130.00 | 38.34 | 42.46 | 41.80 | 40.16 | 38.36 | 36.54 |
| | 132.00 | 35.22 | 40.29 | 40.77 | 39.84 | 38.42 | 36.87 |
| | 134.00 | 32.38 | 38.64 | 40.09 | 38.76 | 38.71 | 37.40 |
| | 136.00 | 28.02 | 35.33 | 37.80 | 38.18 | 37.61 | 36.63 |
| | 138.00 | 27.11 | 34.74 | 37.79 | 38.59 | 38.31 | 37.51 |
| | 140.00 | 24.26 | 32.28 | 35.99 | 37.35 | 37.47 | 38.96 |
| 120.00 | 110.00 | 91.60 | 68.30 | 54.37 | 44.99 | 38.68 | 34.17 |
| | 112.00 | 90.12 | 68.28 | 56.82 | 48.53 | 42.79 | 38.56 |
| | 114.00 | 88.23 | 69.78 | 58.54 | 51.24 | 46.05 | 42.13 |
| | 116.00 | 85.68 | 68.15 | 59.44 | 53.04 | 48.38 | 44.77 |
| | 118.00 | 82.31 | 67.95 | 59.69 | 54.11 | 49.94 | 46.64 |
| | 120.00 | 78.26 | 66.59 | 58.74 | 54.95 | 51.25 | 48.25 |
| | 122.00 | 73.32 | 64.83 | 58.38 | 55.38 | 52.12 | 49.41 |
| | 124.00 | 67.23 | 62.39 | 58.38 | 55.12 | 52.36 | 49.95 |
| | 126.00 | 61.36 | 60.32 | 57.73 | 55.20 | 52.87 | 50.74 |
| | 128.00 | 54.45 | 57.20 | 56.10 | 54.35 | 52.48 | 50.65 |
| | 130.00 | 48.37 | 54.35 | 54.88 | 53.69 | 52.27 | 50.74 |
| | 132.00 | 43.43 | 51.86 | 53.54 | 53.25 | 52.26 | 51.00 |
| | 134.00 | 39.74 | 49.83 | 52.68 | 53.04 | 52.44 | 51.44 |
| | 136.00 | 34.87 | 46.17 | 50.38 | 51.44 | 51.34 | 50.67 |
| | 138.00 | 33.13 | 45.07 | 49.39 | 51.67 | 51.89 | 51.43 |
| | 140.00 | 28.77 | 42.15 | 47.99 | 50.34 | 51.01 | 50.85 |

Table E 18 --continued

| D (min) | Temp(°C) | % Retention<br>Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| 160.00 | 110.00 | 93.62 | 75.92 | 63.27 | 54.89 | 49.01 | 44.66 |
| | 112.00 | 92.66 | 76.30 | 65.38 | 58.09 | 52.86 | 66.90 |
| | 114.00 | 91.01 | 76.27 | 66.84 | 60.49 | 55.84 | 52.25 |
| | 116.00 | 89.01 | 75.72 | 67.59 | 62.06 | 57.94 | 54.66 |
| | 118.00 | 86.30 | 74.66 | 67.76 | 62.97 | 59.32 | 56.37 |
| | 120.00 | 82.37 | 73.48 | 67.76 | 63.68 | 66.47 | 57.81 |
| | 122.00 | 78.78 | 71.92 | 67.41 | 64.00 | 61.21 | 58.94 |
| | 124.00 | 73.40 | 69.75 | 66.49 | 63.76 | 61.40 | 59.30 |
| | 126.00 | 67.90 | 67.84 | 65.86 | 63.79 | 61.82 | 59.99 |
| | 128.00 | 61.16 | 64.95 | 64.37 | 63.00 | 61.45 | 59.89 |
| | 130.00 | 54.89 | 62.23 | 63.04 | 62.37 | 61.24 | 59.95 |
| | 132.00 | 49.53 | 59.75 | 61.91 | 61.92 | 61.19 | 66.16 |
| | 134.00 | 45.29 | 57.61 | 61.01 | 61.67 | 61.31 | 66.53 |
| | 136.00 | 39.73 | 53.91 | 58.74 | 66.18 | 66.29 | 59.81 |
| | 138.00 | 37.66 | 52.53 | 58.30 | 60.38 | 60.74 | 66.46 |
| | 140.00 | 33.93 | 49.41 | 56.30 | 59.02 | 59.90 | 59.92 |
| 200.00 | 110.00 | 94.86 | 80.21 | 69.31 | 61.86 | 56.51 | 52.46 |
| | 112.00 | 93.94 | 80.51 | 71.15 | 66.72 | 60.02 | 56.40 |
| | 114.00 | 92.73 | 80.48 | 72.40 | 66.85 | 62.71 | 59.46 |
| | 116.00 | 91.09 | 79.99 | 73.04 | 66.22 | 66.58 | 61.66 |
| | 118.00 | 88.83 | 79.09 | 73.17 | 69.01 | 65.80 | 63.18 |
| | 120.00 | 86.01 | 78.03 | 73.15 | 69.62 | 66.81 | 64.46 |
| | 122.00 | 82.39 | 76.65 | 72.82 | 69.66 | 67.46 | 65.37 |
| | 124.00 | 77.62 | 74.72 | 71.99 | 69.66 | 67.61 | 65.78 |
| | 126.00 | 72.55 | 72.98 | 71.40 | 69.66 | 67.97 | 66.38 |
| | 128.00 | 66.12 | 70.36 | 70.05 | 68.94 | 67.63 | 66.28 |
| | 130.00 | 59.87 | 67.81 | 66.82 | 68.36 | 67.42 | 66.32 |
| | 132.00 | 54.30 | 65.44 | 67.76 | 67.93 | 67.36 | 66.49 |
| | 134.00 | 49.72 | 63.31 | 66.89 | 67.67 | 67.45 | 66.80 |
| | 136.00 | 43.82 | 59.72 | 64.77 | 66.38 | 66.52 | 66.16 |
| | 138.00 | 41.37 | 58.19 | 64.28 | 66.36 | 66.89 | 66.72 |
| | 140.00 | 37.38 | 55.01 | 62.36 | 65.17 | 66.12 | 66.22 |
| 240.00 | 110.00 | 95.78 | 83.28 | 73.67 | 67.00 | 62.13 | 58.40 |
| | 112.00 | 94.92 | 83.46 | 75.28 | 69.57 | 65.34 | 62.03 |
| | 114.00 | 93.90 | 83.42 | 76.38 | 71.46 | 67.76 | 64.83 |
| | 116.00 | 92.49 | 82.99 | 76.93 | 72.66 | 69.44 | 66.82 |
| | 118.00 | 90.56 | 82.19 | 77.04 | 73.38 | 70.53 | 66.18 |
| | 120.00 | 88.13 | 81.25 | 77.00 | 73.90 | 71.42 | 69.33 |
| | 122.00 | 84.95 | 80.02 | 76.70 | 74.13 | 71.99 | 70.14 |
| | 124.00 | 80.69 | 78.38 | 75.95 | 73.92 | 72.12 | 70.50 |
| | 126.00 | 76.02 | 76.72 | 75.40 | 73.90 | 72.43 | 71.03 |
| | 128.00 | 69.95 | 74.33 | 74.18 | 73.25 | 72.11 | 70.93 |
| | 130.00 | 63.82 | 71.97 | 73.06 | 72.72 | 71.92 | 70.96 |
| | 132.00 | 58.18 | 69.73 | 72.07 | 72.31 | 71.85 | 71.11 |
| | 134.00 | 53.39 | 67.68 | 71.25 | 72.08 | 71.92 | 71.38 |
| | 136.00 | 47.26 | 64.23 | 69.29 | 70.81 | 71.08 | 70.79 |
| | 138.00 | 44.58 | 62.64 | 68.78 | 70.83 | 71.39 | 71.28 |
| | 140.00 | 40.14 | 59.48 | 66.97 | 69.73 | 70.66 | 70.83 |

Table E- 19 Simulated quality retention of foods with thermal diffusivity 1.2x $10^{-7}$ $m^2$ /s after thermal processing in the elliptically shaped container #1 h = 300 w/$m^2$K

% Retention

| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| 40.00 | 110.00 | 76.50 | 31.44 | 14.13 | 7.47 | 4.47 | 2.93 |
| | 112.00 | 73.17 | 32.38 | 16.33 | 9.53 | 6.17 | 4.30 |
| | 114.00 | 68.92 | 32.42 | 17.66 | 11.28 | 7.69 | 5.62 |
| | 116.00 | 63.80 | 31.83 | 18.83 | 12.51 | 8.98 | 6.80 |
| | 118.00 | 57.98 | 30.82 | 19.48 | 13.58 | 10.03 | 7.81 |
| | 120.00 | 51.75 | 29.56 | 19.66 | 14.25 | 10.92 | 8.70 |
| | 122.00 | 45.53 | 28.15 | 19.70 | 14.79 | 11.63 | 9.46 |
| | 124.00 | 39.66 | 26.61 | 19.51 | 15.12 | 12.17 | 10.08 |
| | 126.00 | 34.80 | 25.13 | 19.24 | 15.34 | 12.60 | 10.61 |
| | 128.00 | 30.36 | 23.68 | 18.85 | 15.42 | 12.90 | 11.00 |
| | 130.00 | 26.97 | 22.36 | 18.45 | 15.45 | 13.15 | 11.37 |
| | 132.00 | 24.15 | 21.10 | 17.98 | 15.38 | 13.30 | 11.64 |
| | 134.00 | 21.89 | 19.99 | 17.52 | 15.29 | 13.41 | 11.87 |
| | 136.00 | 20.01 | 19.00 | 17.07 | 15.16 | 13.48 | 12.05 |
| | 138.00 | 18.35 | 18.07 | 16.59 | 14.98 | 13.48 | 12.18 |
| | 140.00 | 16.95 | 17.25 | 16.16 | 14.80 | 13.47 | 12.27 |
| 80.00 | 110.00 | 87.42 | 55.81 | 37.28 | 27.87 | 20.94 | 16.96 |
| | 112.00 | 85.44 | 56.50 | 39.97 | 30.49 | 24.54 | 20.52 |
| | 114.00 | 82.81 | 56.34 | 41.65 | 32.98 | 27.34 | 23.40 |
| | 116.00 | 79.44 | 55.56 | 42.60 | 34.74 | 29.47 | 25.70 |
| | 118.00 | 75.29 | 54.32 | 43.02 | 35.95 | 31.07 | 27.48 |
| | 120.00 | 70.37 | 52.75 | 43.06 | 36.78 | 32.31 | 28.95 |
| | 122.00 | 64.78 | 50.92 | 42.80 | 37.30 | 33.25 | 30.12 |
| | 124.00 | 58.68 | 48.83 | 42.26 | 37.51 | 33.88 | 31.00 |
| | 126.00 | 52.60 | 46.66 | 41.57 | 37.56 | 34.34 | 31.72 |
| | 128.00 | 46.84 | 44.41 | 40.72 | 37.41 | 34.59 | 32.20 |
| | 130.00 | 41.81 | 42.19 | 39.81 | 37.19 | 34.77 | 32.62 |
| | 132.00 | 37.45 | 39.95 | 38.77 | 36.81 | 34.78 | 32.89 |
| | 134.00 | 33.87 | 37.85 | 37.73 | 36.38 | 34.74 | 33.09 |
| | 136.00 | 30.92 | 35.89 | 36.67 | 35.90 | 34.62 | 33.22 |
| | 138.00 | 28.40 | 34.02 | 35.56 | 35.33 | 34.41 | 33.24 |
| | 140.00 | 26.29 | 32.34 | 34.50 | 34.75 | 34.16 | 33.22 |
| 120.00 | 110.00 | 91.42 | 67.71 | 51.70 | 41.75 | 35.18 | 30.58 |
| | 112.00 | 90.02 | 68.23 | 54.12 | 45.17 | 39.09 | 34.70 |
| | 114.00 | 88.13 | 68.05 | 55.59 | 47.57 | 41.98 | 37.87 |
| | 116.00 | 85.67 | 67.34 | 56.38 | 49.21 | 44.12 | 40.26 |
| | 118.00 | 82.54 | 66.23 | 56.67 | 50.30 | 45.67 | 42.11 |
| | 120.00 | 78.69 | 64.81 | 56.62 | 51.02 | 46.85 | 43.57 |
| | 122.00 | 74.07 | 63.11 | 56.30 | 51.44 | 47.70 | 44.71 |
| | 124.00 | 68.70 | 61.13 | 55.69 | 51.56 | 48.26 | 45.55 |
| | 126.00 | 62.89 | 59.01 | 54.94 | 51.52 | 48.65 | 46.21 |
| | 128.00 | 56.93 | 56.71 | 54.02 | 51.30 | 48.83 | 46.65 |
| | 130.00 | 51.29 | 54.36 | 53.02 | 50.99 | 48.93 | 47.02 |
| | 132.00 | 46.14 | 51.90 | 51.87 | 50.52 | 48.88 | 47.23 |
| | 134.00 | 41.75 | 49.49 | 50.68 | 50.00 | 48.76 | 47.37 |
| | 136.00 | 38.06 | 47.13 | 49.45 | 49.41 | 48.57 | 47.44 |
| | 138.00 | 34.91 | 44.81 | 48.14 | 48.73 | 48.27 | 47.40 |
| | 140.00 | 32.29 | 42.64 | 46.83 | 48.02 | 47.94 | 47.33 |

Table E-19--continued

**% Retention**

| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| 160.00 | 110.00 | 93.49 | 74.61 | 60.93 | 51.89 | 45.64 | 41.09 |
| | 112.00 | 92.41 | 75.03 | 63.04 | 55.04 | 49.39 | 45.17 |
| | 114.00 | 90.94 | 74.68 | 64.30 | 57.20 | 52.09 | 48.22 |
| | 116.00 | 89.00 | 74.24 | 64.95 | 58.66 | 54.05 | 50.50 |
| | 118.00 | 86.51 | 73.27 | 65.18 | 59.61 | 55.46 | 52.20 |
| | 120.00 | 83.37 | 72.03 | 65.10 | 60.23 | 56.51 | 53.54 |
| | 122.00 | 79.50 | 70.52 | 64.77 | 60.56 | 57.27 | 54.57 |
| | 124.00 | 74.84 | 68.75 | 64.19 | 60.64 | 57.75 | 55.33 |
| | 126.00 | 69.54 | 66.80 | 63.47 | 60.57 | 58.07 | 55.91 |
| | 128.00 | 63.81 | 64.66 | 62.59 | 60.33 | 58.21 | 56.29 |
| | 130.00 | 58.05 | 62.41 | 61.62 | 60.00 | 58.27 | 56.60 |
| | 132.00 | 52.54 | 59.99 | 60.58 | 59.53 | 58.19 | 56.78 |
| | 134.00 | 47.64 | 57.55 | 59.33 | 59.01 | 58.04 | 56.88 |
| | 136.00 | 43.43 | 55.06 | 58.08 | 58.41 | 57.83 | 56.92 |
| | 138.00 | 39.80 | 52.61 | 56.76 | 57.72 | 57.52 | 56.86 |
| | 140.00 | 36.76 | 50.21 | 55.41 | 57.00 | 57.17 | 56.76 |
| 200.00 | 110.00 | 94.75 | 79.10 | 67.25 | 59.14 | 53.37 | 49.07 |
| | 112.00 | 93.87 | 79.44 | 69.18 | 61.99 | 56.54 | 52.93 |
| | 114.00 | 92.67 | 79.28 | 70.19 | 63.92 | 59.31 | 55.76 |
| | 116.00 | 91.08 | 78.74 | 70.75 | 65.21 | 61.09 | 57.86 |
| | 118.00 | 89.01 | 77.90 | 70.93 | 66.05 | 62.35 | 59.40 |
| | 120.00 | 86.37 | 76.80 | 70.84 | 66.58 | 63.28 | 60.62 |
| | 122.00 | 83.08 | 75.48 | 70.53 | 66.86 | 63.95 | 61.54 |
| | 124.00 | 78.97 | 73.89 | 69.99 | 66.91 | 64.37 | 62.21 |
| | 126.00 | 74.19 | 72.13 | 69.33 | 66.83 | 64.64 | 62.73 |
| | 128.00 | 68.80 | 70.17 | 68.51 | 66.59 | 64.75 | 63.06 |
| | 130.00 | 63.15 | 68.08 | 67.61 | 66.27 | 64.79 | 63.33 |
| | 132.00 | 57.51 | 65.80 | 66.56 | 65.83 | 64.70 | 63.48 |
| | 134.00 | 52.32 | 63.43 | 65.45 | 65.33 | 64.55 | 63.56 |
| | 136.00 | 47.74 | 61.01 | 64.27 | 64.76 | 64.34 | 63.58 |
| | 138.00 | 43.74 | 58.50 | 62.99 | 64.10 | 64.03 | 63.51 |
| | 140.00 | 40.36 | 56.03 | 61.67 | 63.60 | 63.70 | 63.40 |
| 240.00 | 110.00 | 95.61 | 82.24 | 71.83 | 64.54 | 59.25 | 55.24 |
| | 112.00 | 94.87 | 82.53 | 73.47 | 67.12 | 62.44 | 58.84 |
| | 114.00 | 93.85 | 82.39 | 74.43 | 68.85 | 64.69 | 61.45 |
| | 116.00 | 92.50 | 81.91 | 74.92 | 70.00 | 66.29 | 63.36 |
| | 118.00 | 90.73 | 81.17 | 75.07 | 70.74 | 67.43 | 64.77 |
| | 120.00 | 88.45 | 80.19 | 74.97 | 71.20 | 68.26 | 65.88 |
| | 122.00 | 85.56 | 79.03 | 74.68 | 71.45 | 68.85 | 66.70 |
| | 124.00 | 81.94 | 77.59 | 74.19 | 71.48 | 69.22 | 67.30 |
| | 126.00 | 77.61 | 76.00 | 73.58 | 71.39 | 69.46 | 67.76 |
| | 128.00 | 72.59 | 74.21 | 72.83 | 71.16 | 69.55 | 68.05 |
| | 130.00 | 67.15 | 72.28 | 72.00 | 70.87 | 69.57 | 68.29 |
| | 132.00 | 61.53 | 70.14 | 71.03 | 70.45 | 69.48 | 68.41 |
| | 134.00 | 56.18 | 67.90 | 69.99 | 69.98 | 69.33 | 68.47 |
| | 136.00 | 51.34 | 65.57 | 68.88 | 69.45 | 69.13 | 68.48 |
| | 138.00 | 47.85 | 63.11 | 67.67 | 68.83 | 66.84 | 68.41 |
| | 140.00 | 43.39 | 60.65 | 66.41 | 66.17 | 66.52 | 66.30 |

Table E-20 Simulated quality retention of foods with thermal diffusivity 1.4 x $10^{-7}$ $m^2/s$ after thermal processing in the elliptically shaped container #1 h = 300 w/$m^2$K

| D (mm) | Temp(°C) | % Retention<br>Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| 40.00 | 110.00 | 77.49 | 33.60 | 15.98 | 8.87 | 5.54 | 3.77 |
| | 112.00 | 74.43 | 34.82 | 18.54 | 11.34 | 7.65 | 5.53 |
| | 114.00 | 70.53 | 35.11 | 20.36 | 13.35 | 9.51 | 7.18 |
| | 116.00 | 65.74 | 34.87 | 21.54 | 14.92 | 11.09 | 8.66 |
| | 118.00 | 60.24 | 33.79 | 22.28 | 16.14 | 12.41 | 9.95 |
| | 120.00 | 54.15 | 32.53 | 22.60 | 17.00 | 13.45 | 11.03 |
| | 122.00 | 47.92 | 31.10 | 22.67 | 17.62 | 14.28 | 11.92 |
| | 124.00 | 41.93 | 29.52 | 22.52 | 18.03 | 14.93 | 12.87 |
| | 126.00 | 36.58 | 27.93 | 22.22 | 18.28 | 15.44 | 13.38 |
| | 128.00 | 32.03 | 26.35 | 21.80 | 18.39 | 15.81 | 13.80 |
| | 130.00 | 28.38 | 24.91 | 21.38 | 18.44 | 16.11 | 14.24 |
| | 132.00 | 25.32 | 23.50 | 20.82 | 18.36 | 16.28 | 14.56 |
| | 134.00 | 22.89 | 22.25 | 20.28 | 18.22 | 16.37 | 14.78 |
| | 136.00 | 20.81 | 21.06 | 19.70 | 18.02 | 16.41 | 14.96 |
| | 138.00 | 19.12 | 20.03 | 19.17 | 17.83 | 16.42 | 15.12 |
| | 140.00 | 17.63 | 19.09 | 18.63 | 17.59 | 16.39 | 15.22 |
| 80.00 | 110.00 | 88.00 | 57.77 | 39.73 | 29.57 | 23.37 | 19.29 |
| | 112.00 | 86.20 | 58.70 | 42.71 | 33.37 | 27.41 | 23.33 |
| | 114.00 | 83.82 | 58.78 | 44.64 | 36.13 | 30.52 | 26.55 |
| | 116.00 | 80.75 | 58.21 | 45.38 | 38.11 | 32.89 | 29.11 |
| | 118.00 | 76.95 | 57.18 | 46.37 | 39.52 | 34.72 | 31.18 |
| | 120.00 | 72.34 | 55.74 | 46.50 | 40.44 | 36.07 | 32.75 |
| | 122.00 | 67.03 | 54.02 | 46.32 | 41.02 | 37.07 | 33.98 |
| | 124.00 | 61.18 | 52.06 | 45.87 | 41.32 | 37.80 | 34.97 |
| | 126.00 | 55.10 | 49.96 | 45.22 | 41.42 | 38.31 | 35.74 |
| | 128.00 | 49.21 | 47.71 | 44.41 | 41.33 | 38.64 | 36.33 |
| | 130.00 | 43.95 | 45.49 | 43.54 | 41.15 | 38.87 | 36.81 |
| | 132.00 | 39.31 | 43.21 | 42.51 | 40.79 | 38.91 | 37.12 |
| | 134.00 | 35.46 | 41.02 | 41.45 | 40.38 | 38.86 | 37.29 |
| | 136.00 | 32.20 | 38.88 | 40.31 | 39.84 | 38.71 | 37.40 |
| | 138.00 | 29.55 | 36.91 | 39.20 | 39.29 | 38.54 | 37.47 |
| | 140.00 | 27.29 | 35.06 | 38.06 | 38.68 | 38.28 | 37.45 |
| 120.00 | 110.00 | 91.82 | 69.31 | 53.96 | 44.32 | 37.88 | 33.33 |
| | 112.00 | 90.56 | 70.02 | 56.60 | 48.01 | 42.11 | 37.83 |
| | 114.00 | 88.86 | 70.05 | 58.26 | 50.60 | 45.22 | 41.22 |
| | 116.00 | 86.63 | 69.53 | 59.21 | 52.40 | 47.51 | 43.81 |
| | 118.00 | 83.80 | 68.83 | 59.66 | 53.64 | 49.24 | 45.83 |
| | 120.00 | 80.25 | 67.35 | 59.70 | 54.43 | 50.48 | 47.36 |
| | 122.00 | 75.96 | 65.82 | 59.47 | 54.90 | 51.37 | 48.51 |
| | 124.00 | 70.93 | 64.02 | 58.98 | 55.12 | 52.01 | 49.43 |
| | 126.00 | 65.34 | 62.02 | 58.31 | 55.14 | 52.44 | 50.13 |
| | 128.00 | 59.45 | 59.85 | 57.47 | 54.98 | 52.69 | 50.65 |
| | 130.00 | 53.73 | 57.60 | 56.55 | 54.73 | 52.84 | 51.06 |
| | 132.00 | 48.38 | 55.20 | 55.47 | 54.32 | 52.83 | 51.31 |
| | 134.00 | 43.73 | 52.81 | 54.33 | 53.83 | 52.72 | 51.43 |
| | 136.00 | 39.69 | 50.30 | 53.09 | 53.24 | 52.52 | 51.48 |
| | 138.00 | 36.35 | 48.02 | 51.84 | 52.62 | 52.28 | 51.50 |
| | 140.00 | 33.52 | 45.75 | 50.53 | 51.93 | 51.97 | 51.44 |

Table E-20 —continued

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| **D (mm)** | **Temp(°C)** | **Z = 10°C** | **Z = 20°C** | **Z = 30°C** | **Z = 40°C** | **Z = 50°C** | **Z = 60°C** |
| 160.00 | 110.00 | 93.80 | 75.94 | 62.93 | 54.28 | 48.26 | 43.84 |
| | 112.00 | 92.83 | 76.51 | 65.21 | 57.63 | 52.24 | 48.20 |
| | 114.00 | 91.51 | 76.51 | 66.63 | 59.94 | 55.09 | 51.40 |
| | 116.00 | 89.76 | 76.06 | 67.41 | 61.51 | 57.17 | 53.80 |
| | 118.00 | 87.52 | 75.29 | 67.78 | 62.59 | 58.70 | 55.64 |
| | 120.00 | 84.65 | 74.19 | 67.78 | 63.26 | 59.80 | 57.02 |
| | 122.00 | 81.10 | 72.85 | 67.55 | 63.65 | 60.57 | 58.05 |
| | 124.00 | 76.80 | 71.27 | 67.09 | 63.81 | 61.12 | 58.85 |
| | 126.00 | 71.80 | 69.48 | 66.46 | 63.79 | 61.48 | 59.47 |
| | 128.00 | 66.27 | 67.49 | 65.69 | 63.62 | 61.68 | 59.91 |
| | 130.00 | 60.58 | 65.40 | 64.81 | 63.37 | 61.79 | 60.26 |
| | 132.00 | 54.97 | 63.11 | 63.79 | 62.96 | 61.75 | 60.47 |
| | 134.00 | 49.87 | 60.76 | 62.78 | 62.49 | 61.63 | 60.56 |
| | 136.00 | 45.33 | 58.30 | 61.50 | 61.91 | 61.42 | 60.59 |
| | 138.00 | 41.49 | 55.87 | 60.26 | 61.31 | 61.18 | 60.58 |
| | 140.00 | 38.20 | 53.44 | 58.96 | 60.62 | 60.86 | 60.50 |
| 200.00 | 110.00 | 95.01 | 80.22 | 69.02 | 61.32 | 55.81 | 51.69 |
| | 112.00 | 94.21 | 80.70 | 71.01 | 64.32 | 59.46 | 55.76 |
| | 114.00 | 93.14 | 80.78 | 72.23 | 66.37 | 62.04 | 58.70 |
| | 116.00 | 91.71 | 80.38 | 72.90 | 67.75 | 63.90 | 60.87 |
| | 118.00 | 89.85 | 79.63 | 73.21 | 68.69 | 65.26 | 62.53 |
| | 120.00 | 87.45 | 78.67 | 73.19 | 69.27 | 66.23 | 63.76 |
| | 122.00 | 84.44 | 77.50 | 72.97 | 69.60 | 66.91 | 64.68 |
| | 124.00 | 80.70 | 76.10 | 72.55 | 69.72 | 67.38 | 65.39 |
| | 126.00 | 76.25 | 74.51 | 71.98 | 69.69 | 67.69 | 65.92 |
| | 128.00 | 71.14 | 72.72 | 71.26 | 69.52 | 67.85 | 66.31 |
| | 130.00 | 65.67 | 70.80 | 70.47 | 69.28 | 67.94 | 66.61 |
| | 132.00 | 60.03 | 68.67 | 69.52 | 68.90 | 67.89 | 66.78 |
| | 134.00 | 54.71 | 66.45 | 68.51 | 69.46 | 67.76 | 66.85 |
| | 136.00 | 49.83 | 64.08 | 67.39 | 67.92 | 67.56 | 66.87 |
| | 138.00 | 45.62 | 61.69 | 66.23 | 67.35 | 67.33 | 66.85 |
| | 140.00 | 41.98 | 59.24 | 64.98 | 66.71 | 67.03 | 66.77 |
| 240.00 | 110.00 | 95.82 | 83.22 | 73.41 | 66.52 | 61.50 | 57.69 |
| | 112.00 | 95.15 | 83.63 | 75.16 | 69.21 | 64.83 | 61.45 |
| | 114.00 | 94.25 | 83.62 | 76.24 | 71.04 | 67.16 | 64.13 |
| | 116.00 | 93.03 | 83.27 | 76.82 | 72.27 | 68.83 | 66.11 |
| | 118.00 | 91.45 | 82.68 | 77.08 | 73.10 | 70.05 | 67.60 |
| | 120.00 | 89.39 | 81.83 | 77.06 | 73.60 | 70.91 | 68.70 |
| | 122.00 | 86.77 | 80.80 | 76.85 | 73.89 | 71.51 | 69.52 |
| | 124.00 | 83.49 | 79.55 | 76.46 | 73.97 | 71.92 | 70.15 |
| | 126.00 | 79.49 | 78.13 | 75.95 | 73.95 | 72.19 | 70.63 |
| | 128.00 | 74.79 | 76.51 | 75.30 | 73.79 | 72.33 | 70.97 |
| | 130.00 | 69.59 | 74.75 | 74.57 | 73.57 | 72.40 | 71.24 |
| | 132.00 | 64.06 | 72.79 | 73.71 | 73.22 | 72.35 | 71.38 |
| | 134.00 | 58.65 | 70.72 | 72.78 | 72.80 | 72.22 | 71.44 |
| | 136.00 | 53.56 | 68.47 | 71.74 | 72.31 | 72.03 | 71.45 |
| | 138.00 | 49.08 | 66.17 | 70.65 | 71.78 | 71.82 | 71.42 |
| | 140.00 | 45.15 | 63.77 | 69.48 | 71.18 | 71.53 | 71.34 |

Table E-21 Simulated quality retention of foods with thermal diffusivity 1.6 x $10^{-7}$ $m^2/s$ after thermal processing in the elliptically shaped container #1 h = 300 w/$m^2$K

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| D (mm) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 40.00 | 110.00 | 78.29 | 35.27 | 17.48 | 10.07 | 6.49 | 4.54 |
| | 112.00 | 75.46 | 36.88 | 20.48 | 12.98 | 9.02 | 6.70 |
| | 114.00 | 71.86 | 37.42 | 22.86 | 15.34 | 11.25 | 8.72 |
| | 116.00 | 67.34 | 37.12 | 23.96 | 17.13 | 13.09 | 10.47 |
| | 118.00 | 62.11 | 36.36 | 24.83 | 18.52 | 14.60 | 11.96 |
| | 120.00 | 56.28 | 35.22 | 25.30 | 19.56 | 15.84 | 13.25 |
| | 122.00 | 50.05 | 33.73 | 25.37 | 20.24 | 16.78 | 14.29 |
| | 124.00 | 44.01 | 32.16 | 25.26 | 20.74 | 17.54 | 15.17 |
| | 126.00 | 38.45 | 30.50 | 24.96 | 21.03 | 18.12 | 15.89 |
| | 128.00 | 33.65 | 28.84 | 24.52 | 21.15 | 18.51 | 16.42 |
| | 130.00 | 29.72 | 27.27 | 24.03 | 21.19 | 18.84 | 16.91 |
| | 132.00 | 26.45 | 25.73 | 23.44 | 21.18 | 19.03 | 17.27 |
| | 134.00 | 23.81 | 24.33 | 22.83 | 20.96 | 19.16 | 17.56 |
| | 136.00 | 21.63 | 23.83 | 22.28 | 20.75 | 19.21 | 17.78 |
| | 138.00 | 19.86 | 21.86 | 21.86 | 20.52 | 19.23 | 17.95 |
| | 140.00 | 18.25 | 20.79 | 20.56 | 20.22 | 19.16 | 18.04 |
| 80.00 | 110.00 | 88.40 | 59.23 | 41.61 | 31.55 | 25.33 | 21.19 |
| | 112.00 | 86.81 | 60.46 | 44.97 | 35.77 | 29.84 | 25.72 |
| | 114.00 | 84.64 | 60.80 | 47.14 | 38.83 | 33.28 | 29.32 |
| | 116.00 | 81.80 | 60.38 | 48.42 | 40.96 | 35.83 | 32.08 |
| | 118.00 | 78.28 | 59.53 | 49.15 | 42.49 | 37.79 | 34.26 |
| | 120.00 | 74.01 | 58.27 | 49.43 | 43.56 | 39.29 | 36.01 |
| | 122.00 | 68.92 | 56.63 | 49.28 | 44.18 | 40.35 | 37.33 |
| | 124.00 | 63.38 | 54.80 | 48.93 | 44.57 | 41.17 | 38.41 |
| | 126.00 | 57.32 | 52.76 | 48.34 | 44.72 | 41.73 | 39.24 |
| | 128.00 | 51.40 | 50.59 | 47.58 | 44.66 | 42.07 | 39.82 |
| | 130.00 | 45.94 | 48.37 | 46.72 | 44.50 | 42.32 | 40.32 |
| | 132.00 | 41.07 | 46.07 | 45.72 | 44.18 | 42.48 | 40.67 |
| | 134.00 | 36.95 | 43.82 | 44.86 | 43.77 | 42.39 | 40.91 |
| | 136.00 | 33.49 | 41.62 | 43.53 | 43.28 | 42.28 | 41.66 |
| | 138.00 | 30.65 | 39.56 | 42.40 | 42.74 | 42.12 | 41.15 |
| | 140.00 | 28.22 | 37.96 | 41.21 | 42.11 | 41.86 | 41.13 |
| 120.00 | 110.00 | 92.11 | 70.49 | 55.68 | 46.29 | 39.99 | 35.50 |
| | 112.00 | 90.99 | 71.45 | 58.61 | 50.31 | 44.58 | 40.39 |
| | 114.00 | 89.45 | 71.67 | 60.46 | 53.12 | 47.93 | 44.66 |
| | 116.00 | 87.40 | 71.29 | 61.51 | 55.02 | 50.34 | 46.78 |
| | 118.00 | 84.80 | 70.55 | 62.08 | 56.35 | 52.13 | 48.85 |
| | 120.00 | 81.55 | 69.47 | 62.26 | 57.26 | 53.48 | 50.49 |
| | 122.00 | 77.52 | 68.03 | 62.07 | 57.76 | 54.41 | 51.70 |
| | 124.00 | 72.80 | 66.40 | 61.69 | 58.06 | 55.12 | 52.67 |
| | 126.00 | 67.44 | 64.54 | 61.10 | 58.13 | 55.59 | 53.40 |
| | 128.00 | 61.69 | 62.49 | 60.34 | 58.01 | 55.85 | 53.90 |
| | 130.00 | 55.94 | 60.33 | 59.48 | 57.80 | 56.03 | 54.33 |
| | 132.00 | 50.45 | 58.01 | 58.47 | 57.44 | 56.05 | 54.61 |
| | 134.00 | 45.96 | 55.64 | 57.38 | 57.00 | 55.99 | 54.80 |
| | 136.00 | 41.32 | 53.23 | 56.20 | 56.47 | 55.84 | 54.89 |
| | 138.00 | 37.75 | 50.87 | 54.99 | 55.89 | 55.64 | 54.93 |
| | 140.00 | 34.69 | 48.52 | 53.69 | 55.21 | 55.33 | 54.87 |

Table E- 21 --continued

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| **D (min)** | **Temp(°C)** | **Z = 10°C** | **Z = 20°C** | **Z = 30°C** | **Z = 40°C** | **Z = 50°C** | **Z = 60°C** |
| 160.00 | 110.00 | 94.82 | 76.91 | 64.43 | 56.09 | 50.26 | 45.97 |
| | 112.00 | 93.16 | 77.69 | 64.95 | 59.78 | 54.53 | 50.84 |
| | 114.00 | 91.97 | 77.85 | 68.51 | 62.17 | 57.57 | 54.84 |
| | 116.00 | 90.37 | 77.32 | 69.59 | 63.82 | 59.71 | 56.52 |
| | 118.00 | 88.32 | 76.89 | 69.85 | 64.97 | 61.29 | 58.38 |
| | 120.00 | 85.71 | 75.96 | 69.98 | 65.73 | 62.47 | 59.84 |
| | 122.00 | 82.48 | 74.73 | 69.79 | 66.15 | 63.27 | 60.90 |
| | 124.00 | 78.42 | 73.31 | 69.43 | 66.38 | 63.87 | 61.75 |
| | 126.00 | 73.71 | 71.67 | 68.89 | 66.42 | 64.26 | 62.38 |
| | 128.00 | 68.41 | 69.84 | 68.20 | 66.29 | 64.47 | 62.81 |
| | 130.00 | 62.81 | 67.86 | 67.40 | 66.08 | 64.61 | 63.17 |
| | 132.00 | 57.17 | 65.78 | 66.47 | 65.73 | 64.61 | 63.40 |
| | 134.00 | 51.98 | 63.43 | 65.45 | 65.31 | 64.53 | 63.55 |
| | 136.00 | 47.17 | 61.07 | 64.34 | 64.88 | 64.37 | 63.61 |
| | 138.00 | 43.11 | 58.69 | 63.18 | 64.25 | 64.17 | 63.63 |
| | 140.00 | 39.58 | 56.25 | 61.91 | 63.66 | 63.87 | 63.56 |
| 200.00 | 110.00 | 95.18 | 81.05 | 70.34 | 62.96 | 57.66 | 53.69 |
| | 112.00 | 94.48 | 81.78 | 72.52 | 66.17 | 61.54 | 58.31 |
| | 114.00 | 93.51 | 81.83 | 73.87 | 68.35 | 64.27 | 61.10 |
| | 116.00 | 92.20 | 81.54 | 74.62 | 69.79 | 66.17 | 63.33 |
| | 118.00 | 90.51 | 80.99 | 75.01 | 70.78 | 67.57 | 64.99 |
| | 120.00 | 88.34 | 80.19 | 75.10 | 71.44 | 68.59 | 66.28 |
| | 122.00 | 85.55 | 79.12 | 74.92 | 71.79 | 69.29 | 67.22 |
| | 124.00 | 82.12 | 77.88 | 74.60 | 71.98 | 69.81 | 67.98 |
| | 126.00 | 77.96 | 76.43 | 74.11 | 72.00 | 70.14 | 68.51 |
| | 128.00 | 73.13 | 74.80 | 73.48 | 71.88 | 70.32 | 68.88 |
| | 130.00 | 67.83 | 73.01 | 72.76 | 71.67 | 70.43 | 69.19 |
| | 132.00 | 62.27 | 71.04 | 71.91 | 71.35 | 70.41 | 69.38 |
| | 134.00 | 56.85 | 68.93 | 70.98 | 70.97 | 70.34 | 69.51 |
| | 136.00 | 51.83 | 66.69 | 69.96 | 70.50 | 70.18 | 69.55 |
| | 138.00 | 47.41 | 64.39 | 68.88 | 69.99 | 69.99 | 69.56 |
| | 140.00 | 43.52 | 61.98 | 67.78 | 69.39 | 69.71 | 69.49 |
| 240.00 | 110.00 | 95.97 | 83.93 | 74.58 | 67.99 | 63.19 | 59.55 |
| | 112.00 | 95.38 | 84.49 | 76.50 | 70.88 | 66.72 | 63.51 |
| | 114.00 | 94.56 | 84.60 | 77.64 | 72.81 | 69.17 | 66.32 |
| | 116.00 | 93.45 | 84.35 | 78.33 | 74.08 | 70.87 | 68.33 |
| | 118.00 | 92.02 | 83.64 | 78.64 | 74.96 | 72.11 | 69.82 |
| | 120.00 | 90.15 | 83.16 | 78.74 | 75.53 | 73.02 | 70.96 |
| | 122.00 | 87.74 | 82.22 | 78.57 | 75.84 | 73.63 | 71.90 |
| | 124.00 | 84.74 | 81.12 | 78.28 | 76.00 | 74.08 | 72.45 |
| | 126.00 | 81.03 | 79.83 | 77.83 | 76.00 | 74.38 | 72.94 |
| | 128.00 | 76.63 | 78.37 | 77.27 | 75.89 | 74.53 | 73.26 |
| | 130.00 | 71.66 | 76.75 | 76.62 | 75.70 | 74.62 | 73.54 |
| | 132.00 | 66.27 | 74.95 | 75.85 | 75.40 | 74.60 | 73.70 |
| | 134.00 | 60.84 | 73.00 | 75.00 | 75.05 | 74.52 | 73.81 |
| | 136.00 | 55.64 | 70.91 | 74.66 | 74.62 | 74.38 | 73.84 |
| | 138.00 | 51.00 | 68.72 | 73.87 | 74.15 | 74.20 | 73.84 |
| | 140.00 | 46.83 | 66.40 | 71.97 | 73.60 | 73.96 | 73.77 |

Table E-22 Simulated quality retention of foods with thermal diffusivity 1.2 x 10$^{-7}$ m$^2$/s after thermal processing in the elliptically shaped container #1 using Infinite b

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 48.00 | 110.00 | 76.47 | 32.36 | 15.21 | 8.40 | 5.23 | 3.55 |
| | 112.00 | 73.03 | 33.39 | 17.63 | 10.73 | 7.22 | 5.20 |
| | 114.00 | 68.58 | 33.42 | 19.27 | 12.61 | 8.97 | 6.76 |
| | 116.00 | 63.18 | 32.77 | 20.29 | 14.04 | 10.42 | 8.13 |
| | 118.00 | 57.13 | 31.76 | 20.93 | 15.16 | 11.65 | 9.33 |
| | 120.00 | 50.59 | 30.37 | 21.14 | 15.92 | 12.59 | 10.31 |
| | 122.00 | 44.20 | 28.85 | 21.12 | 16.46 | 13.35 | 11.15 |
| | 124.00 | 38.52 | 27.36 | 20.97 | 16.84 | 13.97 | 11.87 |
| | 126.00 | 33.65 | 25.82 | 20.63 | 17.03 | 14.41 | 12.43 |
| | 128.00 | 29.74 | 24.40 | 20.24 | 17.12 | 14.73 | 12.86 |
| | 130.00 | 26.58 | 23.10 | 19.81 | 17.13 | 14.98 | 13.25 |
| | 132.00 | 23.94 | 21.88 | 19.32 | 17.05 | 15.13 | 13.53 |
| | 134.00 | 21.79 | 20.82 | 18.87 | 16.95 | 15.24 | 13.78 |
| | 136.00 | 19.96 | 19.86 | 18.41 | 16.80 | 15.30 | 13.96 |
| | 138.00 | 18.40 | 18.98 | 17.95 | 16.62 | 15.30 | 14.09 |
| | 140.00 | 17.07 | 18.19 | 17.52 | 16.42 | 15.25 | 14.14 |
| 80.00 | 110.00 | 87.40 | 58.00 | 38.66 | 28.69 | 22.66 | 18.66 |
| | 112.00 | 85.35 | 57.33 | 41.49 | 32.34 | 26.54 | 22.56 |
| | 114.00 | 82.57 | 57.14 | 43.22 | 34.95 | 29.51 | 25.66 |
| | 116.00 | 78.97 | 56.27 | 44.14 | 36.74 | 31.73 | 28.09 |
| | 118.00 | 74.57 | 55.00 | 44.58 | 38.03 | 33.44 | 30.02 |
| | 120.00 | 69.23 | 53.25 | 44.51 | 38.79 | 34.65 | 31.49 |
| | 122.00 | 63.21 | 51.24 | 44.14 | 39.23 | 35.55 | 32.65 |
| | 124.00 | 56.90 | 49.10 | 43.58 | 39.46 | 36.22 | 33.59 |
| | 126.00 | 50.65 | 46.78 | 42.77 | 39.42 | 36.62 | 34.26 |
| | 128.00 | 45.85 | 44.44 | 41.84 | 39.22 | 36.85 | 34.74 |
| | 130.00 | 40.30 | 42.14 | 40.84 | 38.92 | 36.96 | 35.13 |
| | 132.00 | 36.32 | 39.88 | 39.73 | 38.48 | 36.93 | 35.36 |
| | 134.00 | 33.88 | 37.81 | 38.63 | 37.99 | 36.84 | 35.53 |
| | 136.00 | 30.33 | 35.88 | 37.50 | 37.43 | 36.65 | 35.60 |
| | 138.00 | 27.96 | 34.12 | 36.37 | 36.81 | 36.39 | 35.59 |
| | 140.00 | 25.93 | 32.53 | 35.28 | 36.16 | 36.06 | 35.48 |
| 128.00 | 110.00 | 91.40 | 68.34 | 52.96 | 43.40 | 37.06 | 32.58 |
| | 112.00 | 89.95 | 68.89 | 55.47 | 46.98 | 41.18 | 36.96 |
| | 114.00 | 87.95 | 68.67 | 56.95 | 49.43 | 44.17 | 40.26 |
| | 116.00 | 85.31 | 67.89 | 57.70 | 51.87 | 46.33 | 42.74 |
| | 118.00 | 81.97 | 66.73 | 58.00 | 52.20 | 47.95 | 44.65 |
| | 120.00 | 77.73 | 65.14 | 57.84 | 52.83 | 49.06 | 46.07 |
| | 122.00 | 72.67 | 63.27 | 57.40 | 53.16 | 49.86 | 47.17 |
| | 124.00 | 66.93 | 61.21 | 56.76 | 53.28 | 50.43 | 48.03 |
| | 126.00 | 60.73 | 58.89 | 55.88 | 53.14 | 50.74 | 48.63 |
| | 128.00 | 54.63 | 56.46 | 54.87 | 52.86 | 50.88 | 49.04 |
| | 130.00 | 49.07 | 53.95 | 53.75 | 52.46 | 50.91 | 49.36 |
| | 132.00 | 44.25 | 51.38 | 52.50 | 51.92 | 50.88 | 49.53 |
| | 134.00 | 40.28 | 48.90 | 51.22 | 51.32 | 50.62 | 49.62 |
| | 136.00 | 36.94 | 46.49 | 49.88 | 50.64 | 50.35 | 49.63 |
| | 138.00 | 34.09 | 44.20 | 48.50 | 49.89 | 50.00 | 49.55 |
| | 140.00 | 31.63 | 42.10 | 47.11 | 49.08 | 49.58 | 49.37 |

Table E- 22 —continued

| D (min) | Temp(°C) | % Retention<br>Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| 160.00 | 110.00 | 93.47 | 75.13 | 62.03 | 53.42 | 47.45 | 43.09 |
| | 112.00 | 92.35 | 75.56 | 64.21 | 56.68 | 51.35 | 47.36 |
| | 114.00 | 90.80 | 75.36 | 65.47 | 58.87 | 54.11 | 50.49 |
| | 116.00 | 88.72 | 74.67 | 66.08 | 60.31 | 56.67 | 52.79 |
| | 118.00 | 86.04 | 73.67 | 66.31 | 61.28 | 57.52 | 54.54 |
| | 120.00 | 82.57 | 72.27 | 66.22 | 61.61 | 58.50 | 55.62 |
| | 122.00 | 78.28 | 70.61 | 65.69 | 62.06 | 59.18 | 56.80 |
| | 124.00 | 73.21 | 68.74 | 65.08 | 62.13 | 59.67 | 57.56 |
| | 126.00 | 67.43 | 66.60 | 64.26 | 61.96 | 59.92 | 56.69 |
| | 128.00 | 61.36 | 66.30 | 63.27 | 61.66 | 60.01 | 56.43 |
| | 130.00 | 55.47 | 61.86 | 62.18 | 61.25 | 60.00 | 58.69 |
| | 132.00 | 50.12 | 59.29 | 60.95 | 60.71 | 59.86 | 58.62 |
| | 134.00 | 45.60 | 56.71 | 59.67 | 60.11 | 59.66 | 58.87 |
| | 136.00 | 41.80 | 54.12 | 58.31 | 59.41 | 59.37 | 56.65 |
| | 138.00 | 38.58 | 51.59 | 56.68 | 58.65 | 59.01 | 58.74 |
| | 140.00 | 35.82 | 49.19 | 55.42 | 57.63 | 58.57 | 58.55 |
| 200.00 | 110.00 | 94.74 | 79.54 | 66.23 | 60.53 | 55.06 | 50.97 |
| | 112.00 | 93.63 | 79.89 | 70.13 | 63.46 | 58.64 | 54.97 |
| | 114.00 | 92.56 | 79.71 | 71.21 | 65.40 | 61.15 | 57.85 |
| | 116.00 | 90.84 | 79.11 | 71.73 | 66.67 | 62.00 | 59.95 |
| | 118.00 | 88.61 | 78.22 | 71.90 | 67.52 | 64.19 | 61.52 |
| | 120.00 | 85.68 | 77.00 | 71.72 | 67.97 | 65.05 | 62.67 |
| | 122.00 | 81.99 | 75.53 | 71.31 | 68.17 | 65.65 | 63.54 |
| | 124.00 | 77.50 | 73.85 | 70.74 | 68.21 | 66.07 | 64.21 |
| | 126.00 | 72.19 | 71.91 | 69.97 | 68.04 | 66.27 | 64.67 |
| | 128.00 | 66.37 | 69.78 | 69.07 | 67.75 | 66.34 | 64.97 |
| | 130.00 | 60.43 | 67.49 | 68.05 | 67.35 | 66.31 | 65.19 |
| | 132.00 | 54.78 | 65.02 | 66.89 | 66.83 | 66.16 | 65.28 |
| | 134.00 | 49.85 | 62.49 | 65.67 | 66.26 | 65.96 | 65.32 |
| | 136.00 | 45.67 | 59.88 | 64.36 | 65.60 | 65.68 | 65.28 |
| | 138.00 | 42.14 | 57.27 | 62.97 | 64.86 | 65.32 | 65.17 |
| | 140.00 | 39.13 | 54.72 | 61.53 | 64.07 | 64.90 | 64.98 |
| 240.00 | 110.00 | 95.60 | 82.62 | 72.70 | 65.80 | 60.80 | 57.02 |
| | 112.00 | 94.83 | 82.92 | 74.38 | 68.44 | 64.08 | 60.72 |
| | 114.00 | 93.75 | 82.76 | 75.33 | 70.17 | 66.35 | 63.26 |
| | 116.00 | 92.29 | 82.22 | 75.78 | 71.30 | 67.93 | 65.26 |
| | 118.00 | 90.39 | 81.44 | 75.92 | 72.04 | 69.08 | 66.68 |
| | 120.00 | 87.85 | 80.35 | 75.74 | 72.43 | 69.84 | 67.72 |
| | 122.00 | 84.62 | 79.04 | 75.37 | 72.60 | 70.37 | 68.49 |
| | 124.00 | 80.61 | 77.53 | 74.84 | 72.62 | 70.74 | 69.09 |
| | 126.00 | 75.75 | 75.77 | 74.13 | 72.46 | 70.91 | 69.49 |
| | 128.00 | 70.24 | 73.82 | 73.30 | 72.16 | 70.96 | 69.75 |
| | 130.00 | 64.39 | 71.69 | 72.36 | 71.81 | 70.92 | 69.94 |
| | 132.00 | 58.61 | 69.36 | 71.29 | 71.33 | 70.76 | 70.02 |
| | 134.00 | 53.39 | 66.92 | 70.14 | 70.79 | 70.54 | 70.06 |
| | 136.00 | 48.89 | 64.38 | 68.90 | 70.17 | 70.31 | 70.00 |
| | 138.00 | 45.00 | 61.77 | 67.58 | 69.47 | 69.98 | 69.89 |
| | 140.00 | 41.87 | 59.17 | 66.19 | 68.72 | 69.54 | 69.70 |

Table E 23 Simulated quality retention of foods with thermal diffusivity $1.4\times10^{-7}\ m^2/s$ after thermal processing in the elliptically shaped container #1 using Infinite h

|  |  | % Retention |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 40.00 | 110.00 | 77.48 | 34.63 | 17.23 | 10.01 | 6.50 | 4.58 |
|  | 112.00 | 74.31 | 35.95 | 20.04 | 12.81 | 8.98 | 6.71 |
|  | 114.00 | 70.29 | 36.34 | 22.18 | 15.13 | 11.19 | 8.72 |
|  | 116.00 | 65.24 | 35.87 | 23.36 | 16.87 | 12.99 | 10.46 |
|  | 118.00 | 59.37 | 34.87 | 24.09 | 18.17 | 14.46 | 11.93 |
|  | 120.00 | 52.94 | 33.50 | 24.39 | 19.08 | 15.60 | 13.15 |
|  | 122.00 | 46.55 | 32.00 | 24.44 | 19.74 | 16.51 | 14.16 |
|  | 124.00 | 40.51 | 30.32 | 24.22 | 20.13 | 17.19 | 14.97 |
|  | 126.00 | 35.40 | 28.71 | 23.89 | 20.39 | 17.73 | 15.66 |
|  | 128.00 | 31.14 | 27.09 | 23.41 | 20.46 | 18.10 | 16.19 |
|  | 130.00 | 27.75 | 25.64 | 22.91 | 20.46 | 18.38 | 16.63 |
|  | 132.00 | 24.97 | 24.28 | 22.35 | 20.34 | 18.52 | 16.92 |
|  | 134.00 | 22.67 | 23.06 | 21.79 | 20.19 | 18.62 | 17.19 |
|  | 136.00 | 20.77 | 21.99 | 21.25 | 20.01 | 18.68 | 17.39 |
|  | 138.00 | 19.11 | 20.98 | 20.69 | 19.76 | 18.65 | 17.52 |
|  | 140.00 | 17.71 | 20.09 | 20.16 | 19.51 | 18.60 | 17.61 |
| 80.00 | 110.00 | 87.99 | 58.63 | 41.24 | 31.39 | 25.31 | 21.25 |
|  | 112.00 | 86.12 | 59.61 | 44.38 | 35.44 | 29.68 | 25.69 |
|  | 114.00 | 83.65 | 59.76 | 46.46 | 38.44 | 33.09 | 29.25 |
|  | 116.00 | 80.37 | 59.12 | 47.60 | 40.48 | 35.58 | 31.98 |
|  | 118.00 | 76.25 | 57.96 | 48.13 | 41.87 | 37.44 | 34.18 |
|  | 120.00 | 71.23 | 56.36 | 48.17 | 42.76 | 38.80 | 35.73 |
|  | 122.00 | 65.50 | 54.52 | 47.93 | 43.31 | 39.80 | 37.08 |
|  | 124.00 | 59.21 | 52.37 | 47.35 | 43.53 | 40.48 | 37.56 |
|  | 126.00 | 52.94 | 50.83 | 46.63 | 43.58 | 40.97 | 38.73 |
|  | 128.00 | 47.05 | 47.73 | 45.69 | 43.39 | 41.23 | 39.27 |
|  | 130.00 | 42.01 | 45.37 | 44.68 | 43.10 | 41.37 | 39.69 |
|  | 132.00 | 37.79 | 43.03 | 43.56 | 42.67 | 41.34 | 39.92 |
|  | 134.00 | 34.33 | 40.81 | 42.40 | 42.16 | 41.25 | 40.09 |
|  | 136.00 | 31.45 | 38.75 | 41.24 | 41.60 | 41.08 | 40.19 |
|  | 138.00 | 28.95 | 36.81 | 40.02 | 40.95 | 40.80 | 40.17 |
|  | 140.00 | 26.82 | 35.06 | 38.83 | 40.26 | 40.48 | 40.11 |
| 120.00 | 110.00 | 91.81 | 68.99 | 55.32 | 46.11 | 39.94 | 35.55 |
|  | 112.00 | 90.50 | 70.73 | 58.06 | 49.97 | 44.41 | 40.34 |
|  | 114.00 | 88.74 | 70.80 | 59.83 | 52.72 | 47.72 | 43.97 |
|  | 116.00 | 86.35 | 70.23 | 60.75 | 54.53 | 50.06 | 46.64 |
|  | 118.00 | 83.25 | 69.21 | 61.13 | 55.74 | 51.76 | 48.66 |
|  | 120.00 | 79.34 | 67.80 | 61.19 | 56.47 | 52.97 | 50.18 |
|  | 122.00 | 74.63 | 66.13 | 60.78 | 56.90 | 53.84 | 51.33 |
|  | 124.00 | 69.08 | 64.14 | 60.18 | 57.02 | 54.41 | 52.19 |
|  | 126.00 | 63.05 | 61.99 | 59.42 | 56.98 | 54.88 | 52.87 |
|  | 128.00 | 56.66 | 59.61 | 58.44 | 56.73 | 54.98 | 53.32 |
|  | 130.00 | 51.09 | 57.15 | 57.38 | 56.37 | 55.04 | 53.66 |
|  | 132.00 | 46.01 | 54.60 | 56.18 | 55.87 | 54.94 | 53.82 |
|  | 134.00 | 41.76 | 52.07 | 54.92 | 55.29 | 54.78 | 53.93 |
|  | 136.00 | 38.25 | 49.59 | 53.60 | 54.65 | 54.55 | 53.96 |
|  | 138.00 | 35.23 | 47.18 | 52.20 | 53.91 | 54.21 | 53.89 |
|  | 140.00 | 32.66 | 44.93 | 50.80 | 53.12 | 53.82 | 53.77 |

Table E- 23 —continued

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 160.00 | 110.00 | 93.79 | 76.50 | 64.11 | 55.92 | 50.21 | 46.82 |
| | 112.00 | 92.78 | 77.09 | 66.46 | 59.39 | 54.35 | 50.58 |
| | 114.00 | 91.41 | 77.13 | 67.96 | 61.81 | 57.36 | 53.95 |
| | 116.00 | 89.54 | 76.63 | 68.72 | 63.38 | 59.45 | 56.38 |
| | 118.00 | 87.08 | 75.75 | 69.02 | 64.41 | 60.94 | 58.20 |
| | 120.00 | 83.90 | 74.53 | 68.94 | 65.02 | 61.99 | 59.54 |
| | 122.00 | 79.96 | 73.07 | 68.64 | 65.36 | 62.74 | 60.56 |
| | 124.00 | 75.13 | 71.31 | 68.07 | 65.44 | 63.22 | 61.38 |
| | 126.00 | 69.63 | 69.36 | 67.36 | 65.36 | 63.53 | 61.88 |
| | 128.00 | 63.61 | 67.17 | 66.45 | 65.10 | 63.66 | 62.26 |
| | 130.00 | 57.66 | 64.84 | 65.45 | 64.75 | 63.69 | 62.54 |
| | 132.00 | 52.08 | 62.36 | 64.31 | 64.26 | 63.57 | 62.66 |
| | 134.00 | 47.28 | 59.81 | 63.08 | 63.70 | 63.40 | 62.73 |
| | 136.00 | 43.26 | 57.24 | 61.79 | 63.07 | 63.15 | 62.74 |
| | 138.00 | 39.84 | 54.65 | 60.39 | 62.34 | 62.81 | 62.65 |
| | 140.00 | 36.94 | 52.15 | 58.96 | 61.56 | 62.42 | 62.51 |
| 200.00 | 110.00 | 95.00 | 80.69 | 70.05 | 62.79 | 57.61 | 53.73 |
| | 112.00 | 94.18 | 81.19 | 72.10 | 65.88 | 61.38 | 57.94 |
| | 114.00 | 93.06 | 81.21 | 73.38 | 68.02 | 64.07 | 61.01 |
| | 116.00 | 91.52 | 80.77 | 74.02 | 69.39 | 65.93 | 63.28 |
| | 118.00 | 89.48 | 80.01 | 74.27 | 70.28 | 67.25 | 64.82 |
| | 120.00 | 86.81 | 78.95 | 74.18 | 70.80 | 68.16 | 66.01 |
| | 122.00 | 83.44 | 77.67 | 73.90 | 71.08 | 68.81 | 66.80 |
| | 124.00 | 79.22 | 76.11 | 73.38 | 71.13 | 69.21 | 67.55 |
| | 126.00 | 74.23 | 74.36 | 72.73 | 71.05 | 69.48 | 68.05 |
| | 128.00 | 68.56 | 72.37 | 71.90 | 70.80 | 69.58 | 68.38 |
| | 130.00 | 62.46 | 70.22 | 70.98 | 70.46 | 69.59 | 68.61 |
| | 132.00 | 56.86 | 67.88 | 69.93 | 70.01 | 69.47 | 68.71 |
| | 134.00 | 51.68 | 65.43 | 68.78 | 69.48 | 69.29 | 68.76 |
| | 136.00 | 47.26 | 62.90 | 67.56 | 68.89 | 69.06 | 68.75 |
| | 138.00 | 43.50 | 60.29 | 66.23 | 68.28 | 68.74 | 68.66 |
| | 140.00 | 40.33 | 57.70 | 64.85 | 67.47 | 68.37 | 68.52 |
| 240.00 | 110.00 | 95.82 | 83.62 | 74.32 | 67.85 | 63.15 | 59.58 |
| | 112.00 | 95.12 | 84.15 | 76.12 | 70.61 | 66.57 | 63.45 |
| | 114.00 | 94.18 | 84.06 | 77.24 | 72.51 | 68.99 | 66.23 |
| | 116.00 | 92.87 | 83.67 | 77.80 | 73.72 | 70.65 | 68.21 |
| | 118.00 | 91.13 | 83.00 | 78.00 | 74.50 | 71.82 | 69.65 |
| | 120.00 | 88.83 | 82.06 | 77.92 | 74.95 | 72.63 | 70.71 |
| | 122.00 | 85.90 | 80.93 | 77.66 | 75.20 | 73.20 | 71.50 |
| | 124.00 | 82.15 | 79.54 | 77.19 | 75.23 | 73.55 | 72.08 |
| | 126.00 | 77.63 | 77.97 | 76.60 | 75.14 | 73.78 | 72.52 |
| | 128.00 | 72.33 | 76.16 | 75.84 | 74.91 | 73.86 | 72.81 |
| | 130.00 | 66.59 | 74.18 | 75.00 | 74.60 | 73.85 | 73.01 |
| | 132.00 | 60.76 | 72.01 | 74.03 | 74.18 | 73.74 | 73.08 |
| | 134.00 | 55.33 | 69.69 | 72.97 | 73.69 | 73.57 | 73.12 |
| | 136.00 | 50.59 | 67.26 | 71.84 | 73.14 | 73.35 | 73.11 |
| | 138.00 | 46.54 | 64.70 | 70.59 | 72.51 | 73.05 | 73.02 |
| | 140.00 | 43.14 | 62.12 | 69.28 | 71.82 | 72.71 | 72.89 |

Table E- 24 Simulated quality retention of foods with thermal diffusivity 1.6x10$^{-7}$ m$^2$/s after thermal processing in the elliptically shaped container #1 using Infinite h

|  |  | % Retention |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 40.00 | 110.00 | 78.26 | 36.48 | 18.95 | 11.43 | 7.67 | 5.56 |
|  | 112.00 | 75.37 | 38.13 | 22.19 | 14.70 | 10.63 | 8.16 |
|  | 114.00 | 71.61 | 38.75 | 24.54 | 17.40 | 13.25 | 10.60 |
|  | 116.00 | 66.87 | 38.47 | 26.05 | 19.43 | 15.37 | 12.66 |
|  | 118.00 | 61.27 | 37.60 | 26.94 | 20.93 | 17.09 | 14.42 |
|  | 120.00 | 55.01 | 36.30 | 27.35 | 22.01 | 18.43 | 15.85 |
|  | 122.00 | 48.60 | 34.79 | 27.45 | 22.77 | 19.49 | 17.05 |
|  | 124.00 | 42.39 | 33.05 | 27.22 | 23.21 | 20.26 | 17.98 |
|  | 126.00 | 37.03 | 31.35 | 26.89 | 23.50 | 20.85 | 18.73 |
|  | 128.00 | 32.53 | 29.64 | 26.39 | 23.60 | 21.27 | 19.34 |
|  | 130.00 | 28.88 | 28.00 | 25.79 | 23.56 | 21.55 | 19.81 |
|  | 132.00 | 25.95 | 26.52 | 25.18 | 23.45 | 21.75 | 20.20 |
|  | 134.00 | 23.53 | 25.17 | 24.53 | 23.26 | 21.85 | 20.48 |
|  | 136.00 | 21.48 | 23.93 | 23.87 | 23.01 | 21.87 | 20.68 |
|  | 138.00 | 19.75 | 22.82 | 23.23 | 22.72 | 21.83 | 20.82 |
|  | 140.00 | 18.32 | 21.86 | 22.64 | 22.43 | 21.77 | 20.92 |
| 80.00 | 110.00 | 88.44 | 60.22 | 43.31 | 33.61 | 27.54 | 23.44 |
|  | 112.00 | 86.75 | 61.47 | 46.79 | 38.06 | 32.37 | 28.38 |
|  | 114.00 | 84.48 | 61.83 | 49.09 | 41.33 | 36.10 | 32.32 |
|  | 116.00 | 81.46 | 61.40 | 50.43 | 43.58 | 38.82 | 35.28 |
|  | 118.00 | 77.62 | 60.42 | 51.11 | 45.12 | 40.85 | 37.59 |
|  | 120.00 | 72.90 | 58.99 | 51.28 | 46.13 | 42.33 | 39.36 |
|  | 122.00 | 67.41 | 57.26 | 51.11 | 46.77 | 43.44 | 40.75 |
|  | 124.00 | 61.25 | 55.19 | 50.59 | 47.04 | 44.17 | 41.78 |
|  | 126.00 | 54.98 | 53.01 | 49.92 | 47.13 | 44.69 | 42.56 |
|  | 128.00 | 48.96 | 50.66 | 49.64 | 46.99 | 45.00 | 43.15 |
|  | 130.00 | 43.62 | 48.23 | 48.01 | 46.70 | 45.14 | 43.57 |
|  | 132.00 | 39.19 | 45.85 | 46.91 | 46.30 | 45.17 | 43.89 |
|  | 134.00 | 35.52 | 43.53 | 45.73 | 45.80 | 45.08 | 44.07 |
|  | 136.00 | 32.44 | 41.31 | 44.49 | 45.20 | 44.90 | 44.16 |
|  | 138.00 | 29.84 | 39.24 | 43.24 | 44.55 | 44.63 | 44.16 |
|  | 140.00 | 27.66 | 37.39 | 42.02 | 43.87 | 44.33 | 44.12 |
| 120.00 | 110.00 | 92.13 | 71.27 | 57.18 | 48.28 | 42.27 | 37.97 |
|  | 112.00 | 90.95 | 72.22 | 60.17 | 52.43 | 47.87 | 43.13 |
|  | 114.00 | 89.33 | 72.46 | 62.10 | 55.37 | 50.60 | 47.01 |
|  | 116.00 | 87.14 | 72.07 | 63.18 | 57.33 | 53.09 | 49.83 |
|  | 118.00 | 84.29 | 71.22 | 63.70 | 58.64 | 54.90 | 51.96 |
|  | 120.00 | 80.67 | 69.98 | 63.77 | 59.47 | 56.28 | 53.57 |
|  | 122.00 | 76.23 | 68.46 | 63.55 | 59.97 | 57.14 | 54.80 |
|  | 124.00 | 70.92 | 66.60 | 63.02 | 60.14 | 57.74 | 55.69 |
|  | 126.00 | 63.66 | 64.57 | 62.34 | 60.15 | 58.15 | 56.36 |
|  | 128.00 | 58.90 | 62.31 | 61.46 | 59.96 | 58.38 | 56.85 |
|  | 130.00 | 52.95 | 59.89 | 60.42 | 59.62 | 58.44 | 57.19 |
|  | 132.00 | 47.67 | 57.40 | 59.30 | 59.18 | 58.41 | 57.42 |
|  | 134.00 | 43.18 | 54.85 | 58.07 | 58.64 | 58.27 | 57.55 |
|  | 136.00 | 39.42 | 52.30 | 56.75 | 57.99 | 58.04 | 57.57 |
|  | 138.00 | 36.26 | 49.82 | 55.37 | 57.28 | 57.73 | 57.52 |
|  | 140.00 | 33.62 | 47.50 | 53.98 | 56.54 | 57.38 | 57.43 |

Table E- 24 --continued

| D (min) | Temp(°C) | % Retention<br>Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| 160.00 | 110.00 | 94.03 | 77.55 | 65.73 | 57.89 | 52.40 | 48.35 |
| | 112.00 | 93.12 | 78.32 | 68.28 | 61.58 | 56.79 | 53.19 |
| | 114.00 | 91.87 | 78.49 | 69.90 | 64.13 | 59.95 | 56.74 |
| | 116.00 | 90.16 | 78.15 | 70.80 | 65.82 | 62.14 | 59.26 |
| | 118.00 | 87.91 | 77.42 | 71.20 | 66.93 | 63.71 | 61.15 |
| | 120.00 | 84.98 | 76.37 | 71.24 | 67.62 | 64.82 | 62.55 |
| | 122.00 | 81.31 | 75.05 | 71.02 | 68.02 | 65.83 | 63.62 |
| | 124.00 | 76.75 | 73.43 | 70.51 | 68.15 | 66.13 | 64.38 |
| | 126.00 | 71.48 | 71.62 | 69.90 | 68.12 | 66.46 | 64.95 |
| | 128.00 | 65.83 | 69.58 | 69.09 | 67.92 | 66.63 | 65.38 |
| | 130.00 | 59.59 | 67.33 | 68.24 | 67.59 | 66.67 | 65.63 |
| | 132.00 | 53.90 | 64.97 | 67.09 | 67.18 | 66.62 | 65.82 |
| | 134.00 | 48.86 | 62.47 | 65.93 | 66.66 | 66.47 | 65.91 |
| | 136.00 | 44.58 | 59.90 | 64.67 | 66.05 | 66.23 | 65.91 |
| | 138.00 | 40.99 | 57.30 | 63.31 | 65.37 | 65.93 | 65.85 |
| | 140.00 | 37.99 | 54.79 | 61.96 | 64.65 | 65.59 | 65.75 |
| 200.00 | 110.00 | 95.20 | 81.58 | 71.47 | 64.56 | 59.62 | 55.90 |
| | 112.00 | 94.46 | 82.22 | 73.68 | 67.83 | 63.58 | 60.33 |
| | 114.00 | 93.44 | 82.36 | 75.00 | 70.07 | 66.39 | 63.53 |
| | 116.00 | 92.03 | 82.06 | 75.82 | 71.53 | 68.31 | 65.78 |
| | 118.00 | 90.17 | 81.44 | 76.16 | 72.48 | 69.89 | 67.44 |
| | 120.00 | 87.72 | 80.52 | 76.17 | 73.07 | 70.65 | 68.67 |
| | 122.00 | 84.60 | 79.37 | 75.96 | 73.41 | 71.34 | 69.60 |
| | 124.00 | 80.65 | 77.95 | 75.52 | 73.50 | 71.77 | 70.26 |
| | 126.00 | 75.92 | 76.35 | 74.96 | 73.46 | 72.05 | 70.75 |
| | 128.00 | 70.48 | 74.52 | 74.23 | 73.28 | 72.19 | 71.10 |
| | 130.00 | 64.59 | 72.47 | 73.36 | 72.97 | 72.21 | 71.33 |
| | 132.00 | 58.77 | 70.28 | 72.41 | 72.58 | 72.15 | 71.49 |
| | 134.00 | 53.38 | 67.92 | 71.34 | 72.10 | 72.00 | 71.55 |
| | 136.00 | 48.69 | 65.44 | 70.17 | 71.54 | 71.78 | 71.55 |
| | 138.00 | 44.74 | 62.87 | 68.92 | 70.92 | 71.50 | 71.48 |
| | 140.00 | 41.45 | 60.32 | 67.62 | 70.25 | 71.18 | 71.38 |
| 240.00 | 110.00 | 95.98 | 84.39 | 75.57 | 69.43 | 64.97 | 61.59 |
| | 112.00 | 95.36 | 84.94 | 77.51 | 72.35 | 68.55 | 65.82 |
| | 114.00 | 94.50 | 85.00 | 78.72 | 74.33 | 71.06 | 68.51 |
| | 116.00 | 93.31 | 84.79 | 79.38 | 75.81 | 72.78 | 70.52 |
| | 118.00 | 91.72 | 84.24 | 79.66 | 76.45 | 73.99 | 72.00 |
| | 120.00 | 89.62 | 83.44 | 79.67 | 76.96 | 74.64 | 73.09 |
| | 122.00 | 86.91 | 82.43 | 79.48 | 77.25 | 75.44 | 73.91 |
| | 124.00 | 83.43 | 81.17 | 79.08 | 77.33 | 75.82 | 74.49 |
| | 126.00 | 79.18 | 79.74 | 78.57 | 77.28 | 76.08 | 74.92 |
| | 128.00 | 74.14 | 78.08 | 77.91 | 77.11 | 76.17 | 75.23 |
| | 130.00 | 68.50 | 76.23 | 77.12 | 76.82 | 76.18 | 75.43 |
| | 132.00 | 62.70 | 74.21 | 76.25 | 76.47 | 76.12 | 75.56 |
| | 134.00 | 57.12 | 72.01 | 75.28 | 76.03 | 75.98 | 75.61 |
| | 136.00 | 52.13 | 69.65 | 74.21 | 75.52 | 75.78 | 75.59 |
| | 138.00 | 47.87 | 67.18 | 73.04 | 74.96 | 75.51 | 75.53 |
| | 140.00 | 44.32 | 64.66 | 71.82 | 74.33 | 75.22 | 75.43 |

Table E- 25 Simulated quality retention of foods with thermal diffusivity $1.2 \times 10^{-7}$ m$^2$/s after thermal processing in the elliptically shaped container #2, h = 300 w/m$^2$K

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| P (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 40.00 | 110.00 | 79.06 | 37.50 | 19.61 | 11.84 | 7.95 | 5.76 |
| | 112.00 | 76.57 | 39.45 | 23.87 | 15.29 | 11.05 | 8.48 |
| | 114.00 | 73.31 | 40.34 | 25.62 | 18.15 | 13.81 | 11.04 |
| | 116.00 | 69.19 | 40.35 | 27.33 | 20.35 | 16.09 | 13.25 |
| | 118.00 | 64.29 | 39.76 | 28.42 | 22.01 | 17.91 | 15.00 |
| | 120.00 | 58.73 | 38.74 | 29.83 | 23.25 | 19.48 | 16.65 |
| | 122.00 | 52.79 | 37.43 | 29.30 | 24.16 | 20.58 | 17.96 |
| | 124.00 | 46.79 | 35.90 | 29.27 | 24.77 | 21.50 | 19.03 |
| | 126.00 | 41.15 | 34.24 | 29.81 | 25.15 | 22.20 | 19.89 |
| | 128.00 | 36.21 | 32.56 | 28.62 | 25.37 | 22.74 | 20.61 |
| | 130.00 | 31.99 | 30.85 | 28.08 | 25.41 | 23.11 | 21.17 |
| | 132.00 | 28.59 | 29.27 | 27.50 | 25.38 | 23.39 | 21.63 |
| | 134.00 | 25.80 | 27.76 | 26.86 | 25.23 | 23.51 | 21.92 |
| | 136.00 | 23.49 | 26.35 | 26.18 | 25.02 | 23.60 | 22.19 |
| | 138.00 | 21.57 | 25.08 | 25.51 | 24.76 | 23.62 | 22.39 |
| | 140.00 | 19.93 | 23.91 | 24.83 | 24.47 | 23.58 | 22.54 |
| 80.00 | 110.00 | 88.90 | 61.12 | 44.12 | 34.27 | 28.08 | 23.90 |
| | 112.00 | 87.46 | 62.62 | 47.80 | 38.90 | 33.07 | 28.99 |
| | 114.00 | 85.52 | 63.22 | 50.30 | 42.32 | 36.93 | 33.04 |
| | 116.00 | 82.97 | 63.89 | 51.85 | 44.75 | 39.82 | 36.17 |
| | 118.00 | 79.76 | 62.44 | 52.75 | 46.46 | 41.97 | 38.56 |
| | 120.00 | 75.81 | 61.37 | 53.17 | 47.66 | 43.61 | 40.47 |
| | 122.00 | 71.15 | 59.99 | 53.23 | 48.47 | 44.86 | 41.98 |
| | 124.00 | 65.83 | 58.33 | 52.99 | 48.96 | 45.77 | 43.16 |
| | 126.00 | 60.87 | 56.44 | 52.51 | 49.19 | 46.42 | 44.07 |
| | 128.00 | 54.26 | 54.41 | 51.86 | 49.25 | 46.88 | 44.80 |
| | 130.00 | 48.69 | 52.22 | 51.04 | 49.11 | 47.15 | 45.33 |
| | 132.00 | 43.75 | 50.82 | 50.14 | 48.88 | 47.32 | 45.75 |
| | 134.00 | 39.49 | 47.80 | 49.13 | 48.51 | 47.32 | 45.97 |
| | 136.00 | 35.89 | 45.60 | 48.05 | 48.07 | 47.26 | 46.16 |
| | 138.00 | 32.89 | 43.47 | 46.93 | 47.56 | 47.13 | 46.28 |
| | 140.00 | 30.37 | 41.44 | 45.78 | 46.99 | 46.92 | 46.32 |
| 120.00 | 110.00 | 92.45 | 71.99 | 57.91 | 48.92 | 42.84 | 38.48 |
| | 112.00 | 91.44 | 73.14 | 61.07 | 53.22 | 47.77 | 43.75 |
| | 114.00 | 90.08 | 73.58 | 63.16 | 56.29 | 51.41 | 47.74 |
| | 116.00 | 88.25 | 73.44 | 64.42 | 58.60 | 54.04 | 50.69 |
| | 118.00 | 85.90 | 72.88 | 65.13 | 59.86 | 55.94 | 52.89 |
| | 120.00 | 82.93 | 71.98 | 65.43 | 60.85 | 57.38 | 54.61 |
| | 122.00 | 79.28 | 70.80 | 65.42 | 61.51 | 58.44 | 55.54 |
| | 124.00 | 74.91 | 69.35 | 65.16 | 61.88 | 59.21 | 56.97 |
| | 126.00 | 69.88 | 67.68 | 64.68 | 62.03 | 59.74 | 57.76 |
| | 128.00 | 64.39 | 65.82 | 64.06 | 62.03 | 60.11 | 58.37 |
| | 130.00 | 58.70 | 63.78 | 63.26 | 61.85 | 60.37 | 58.80 |
| | 132.00 | 53.27 | 61.64 | 62.39 | 61.59 | 60.41 | 59.14 |
| | 134.00 | 48.30 | 59.39 | 61.40 | 61.21 | 60.36 | 59.31 |
| | 136.00 | 43.95 | 57.88 | 60.32 | 60.75 | 60.27 | 59.45 |
| | 138.00 | 40.23 | 54.76 | 59.18 | 60.23 | 60.10 | 59.51 |
| | 140.00 | 37.89 | 52.46 | 57.98 | 59.64 | 59.87 | 59.51 |

Table E- 25 --continued

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 180.00 | 110.00 | 66.28 | 78.14 | 66.37 | 58.48 | 52.93 | 48.66 |
| | 112.00 | 93.51 | 79.07 | 69.06 | 62.29 | 57.43 | 53.78 |
| | 114.00 | 92.45 | 79.42 | 70.81 | 64.95 | 60.38 | 57.40 |
| | 116.00 | 91.03 | 79.29 | 71.86 | 66.76 | 62.98 | 60.04 |
| | 118.00 | 89.18 | 78.91 | 72.43 | 67.99 | 64.64 | 61.78 |
| | 120.00 | 86.82 | 78.05 | 72.66 | 68.83 | 65.87 | 63.48 |
| | 122.00 | 83.85 | 77.04 | 72.63 | 69.37 | 66.78 | 64.63 |
| | 124.00 | 80.20 | 75.80 | 72.39 | 69.67 | 67.42 | 65.51 |
| | 126.00 | 75.66 | 74.35 | 71.95 | 69.78 | 67.86 | 66.18 |
| | 128.00 | 70.87 | 72.72 | 71.39 | 69.75 | 68.16 | 66.78 |
| | 130.00 | 65.45 | 70.89 | 70.67 | 69.58 | 68.31 | 67.06 |
| | 132.00 | 59.96 | 68.93 | 69.88 | 69.33 | 68.38 | 67.34 |
| | 134.00 | 54.70 | 66.84 | 68.97 | 68.97 | 68.33 | 67.47 |
| | 136.00 | 49.91 | 64.63 | 67.98 | 68.54 | 68.22 | 67.57 |
| | 138.00 | 45.72 | 62.35 | 66.92 | 68.06 | 68.06 | 67.62 |
| | 140.00 | 42.11 | 60.02 | 65.78 | 67.51 | 67.84 | 67.66 |
| 200.00 | 110.00 | 95.40 | 82.00 | 72.03 | 65.09 | 60.10 | 56.36 |
| | 112.00 | 94.77 | 82.86 | 74.35 | 68.46 | 64.16 | 60.87 |
| | 114.00 | 93.91 | 83.15 | 75.85 | 70.78 | 67.04 | 64.13 |
| | 116.00 | 92.75 | 83.03 | 76.74 | 72.35 | 69.07 | 66.48 |
| | 118.00 | 91.23 | 82.62 | 77.22 | 73.42 | 70.51 | 68.18 |
| | 120.00 | 89.26 | 81.96 | 77.41 | 74.13 | 71.58 | 69.50 |
| | 122.00 | 86.77 | 81.10 | 77.37 | 74.59 | 72.36 | 70.50 |
| | 124.00 | 83.65 | 80.02 | 77.15 | 74.84 | 72.91 | 71.27 |
| | 126.00 | 79.66 | 78.75 | 76.78 | 74.92 | 73.29 | 71.86 |
| | 128.00 | 75.37 | 77.32 | 76.26 | 74.88 | 73.54 | 72.28 |
| | 130.00 | 70.38 | 75.68 | 75.62 | 74.72 | 73.66 | 72.59 |
| | 132.00 | 66.97 | 73.92 | 74.98 | 74.49 | 73.71 | 72.83 |
| | 134.00 | 59.63 | 72.00 | 74.09 | 74.17 | 73.65 | 72.94 |
| | 136.00 | 54.88 | 69.94 | 73.19 | 73.78 | 73.55 | 73.02 |
| | 138.00 | 50.09 | 67.78 | 72.21 | 73.34 | 73.40 | 73.05 |
| | 140.00 | 46.15 | 65.53 | 71.17 | 72.83 | 73.19 | 73.03 |
| 240.00 | 110.00 | 96.15 | 84.83 | 76.07 | 69.91 | 65.42 | 62.00 |
| | 112.00 | 95.62 | 85.49 | 78.10 | 72.91 | 69.07 | 66.11 |
| | 114.00 | 94.90 | 85.73 | 79.41 | 74.97 | 71.65 | 69.05 |
| | 116.00 | 93.91 | 85.63 | 80.19 | 76.35 | 73.45 | 71.15 |
| | 118.00 | 92.62 | 85.27 | 80.66 | 77.28 | 74.72 | 72.66 |
| | 120.00 | 90.95 | 84.70 | 80.76 | 77.90 | 75.66 | 73.83 |
| | 122.00 | 88.80 | 83.94 | 80.72 | 78.30 | 76.35 | 74.71 |
| | 124.00 | 86.09 | 82.99 | 80.51 | 78.51 | 76.83 | 75.39 |
| | 126.00 | 82.71 | 81.87 | 80.17 | 78.58 | 77.15 | 75.89 |
| | 128.00 | 78.67 | 80.59 | 79.72 | 78.54 | 77.37 | 76.28 |
| | 130.00 | 73.97 | 79.13 | 79.14 | 78.39 | 77.47 | 76.55 |
| | 132.00 | 68.86 | 77.53 | 78.50 | 78.18 | 77.51 | 76.75 |
| | 134.00 | 63.57 | 75.78 | 77.76 | 77.88 | 77.46 | 76.86 |
| | 136.00 | 58.40 | 73.88 | 76.95 | 77.53 | 77.36 | 76.91 |
| | 138.00 | 53.71 | 71.85 | 76.06 | 77.13 | 77.22 | 76.93 |
| | 140.00 | 49.51 | 69.71 | 75.10 | 76.67 | 77.03 | 76.91 |

Table E- 26 Simulated quality retention of foods with thermal diffusivity $1.4 \times 10^{-7}$ $m^2/s$ after thermal processing in the elliptically shaped container #2, h = 300 $w/m^2K$

|  |  | % Retention |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| D (mm) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 40.00 | 110.00 | 79.73 | 39.22 | 21.30 | 13.30 | 9.19 | 6.83 |
|  | 112.00 | 77.51 | 41.57 | 25.25 | 17.28 | 12.83 | 10.07 |
|  | 114.00 | 74.55 | 42.76 | 28.17 | 20.56 | 16.04 | 13.10 |
|  | 116.00 | 70.79 | 43.05 | 30.18 | 23.12 | 18.71 | 15.72 |
|  | 118.00 | 64.22 | 42.65 | 31.48 | 25.04 | 20.85 | 17.91 |
|  | 120.00 | 60.93 | 41.74 | 32.23 | 26.46 | 22.54 | 19.71 |
|  | 122.00 | 55.14 | 40.48 | 32.56 | 27.45 | 23.82 | 21.11 |
|  | 124.00 | 49.12 | 38.95 | 22.56 | 28.12 | 24.84 | 22.30 |
|  | 126.00 | 43.39 | 37.31 | 32.37 | 28.59 | 25.65 | 23.50 |
|  | 128.00 | 38.17 | 35.56 | 31.97 | 28.84 | 26.24 | 24.89 |
|  | 130.00 | 33.72 | 33.82 | 31.45 | 28.54 | 26.69 | 24.73 |
|  | 132.00 | 30.04 | 32.12 | 30.85 | 28.92 | 27.00 | 25.26 |
|  | 134.00 | 27.01 | 30.49 | 30.17 | 28.79 | 27.28 | 25.64 |
|  | 136.00 | 24.52 | 28.95 | 29.44 | 28.58 | 27.31 | 25.97 |
|  | 138.00 | 22.49 | 27.55 | 28.72 | 28.32 | 27.35 | 26.21 |
|  | 140.00 | 20.73 | 26.22 | 27.95 | 27.98 | 27.30 | 26.36 |
| 80.00 | 110.00 | 89.28 | 62.54 | 46.83 | 36.36 | 30.23 | 26.06 |
|  | 112.00 | 88.01 | 64.33 | 50.07 | 41.41 | 35.68 | 31.63 |
|  | 114.00 | 86.27 | 65.17 | 52.83 | 45.13 | 39.87 | 36.85 |
|  | 116.00 | 83.98 | 65.28 | 54.61 | 47.80 | 43.02 | 39.46 |
|  | 118.00 | 81.85 | 64.82 | 55.67 | 49.68 | 45.37 | 42.09 |
|  | 120.00 | 77.42 | 63.92 | 56.21 | 50.99 | 47.13 | 64.12 |
|  | 122.00 | 73.05 | 62.68 | 56.35 | 51.85 | 48.40 | 45.63 |
|  | 124.00 | 67.99 | 61.14 | 56.17 | 52.38 | 49.35 | 46.85 |
|  | 126.00 | 62.47 | 59.40 | 55.80 | 52.70 | 50.08 | 47.84 |
|  | 128.00 | 56.69 | 57.46 | 55.21 | 52.80 | 50.57 | 46.59 |
|  | 130.00 | 51.87 | 55.40 | 54.49 | 52.74 | 50.91 | 49.18 |
|  | 132.00 | 45.92 | 53.25 | 53.65 | 52.56 | 51.11 | 49.64 |
|  | 134.00 | 41.40 | 51.04 | 52.70 | 52.26 | 51.28 | 49.96 |
|  | 136.00 | 37.54 | 48.82 | 51.64 | 51.64 | 51.17 | 50.19 |
|  | 138.00 | 34.32 | 46.66 | 50.58 | 51.46 | 51.00 | 50.34 |
|  | 140.00 | 31.59 | 64.54 | 49.63 | 50.84 | 50.90 | 50.40 |
| 120.00 | 110.00 | 92.71 | 73.10 | 59.58 | 50.90 | 45.01 | 40.77 |
|  | 112.00 | 91.83 | 74.48 | 63.01 | 55.51 | 50.26 | 46.39 |
|  | 114.00 | 90.60 | 75.11 | 65.28 | 58.77 | 54.12 | 50.61 |
|  | 116.00 | 88.97 | 75.16 | 66.72 | 61.05 | 56.92 | 53.75 |
|  | 118.00 | 86.85 | 74.77 | 67.55 | 62.62 | 58.96 | 56.09 |
|  | 120.00 | 84.15 | 74.02 | 67.95 | 63.70 | 60.46 | 57.87 |
|  | 122.00 | 80.79 | 72.98 | 68.02 | 64.38 | 61.52 | 59.17 |
|  | 124.00 | 76.72 | 71.68 | 67.83 | 64.80 | 62.31 | 60.21 |
|  | 126.00 | 72.02 | 70.18 | 67.46 | 65.03 | 62.90 | 61.04 |
|  | 128.00 | 64.74 | 68.47 | 66.92 | 65.06 | 63.29 | 61.66 |
|  | 130.00 | 61.19 | 66.60 | 66.24 | 64.97 | 63.54 | 62.15 |
|  | 132.00 | 55.71 | 64.59 | 65.45 | 64.77 | 63.68 | 62.51 |
|  | 134.00 | 50.57 | 62.45 | 64.55 | 64.46 | 63.71 | 62.76 |
|  | 136.00 | 45.98 | 66.23 | 63.56 | 64.06 | 63.64 | 62.93 |
|  | 138.00 | 42.04 | 57.97 | 62.51 | 63.61 | 63.54 | 63.03 |
|  | 140.00 | 38.63 | 55.67 | 61.37 | 63.06 | 63.34 | 63.05 |

Table E- 26 —continued

| D (mm) | Temp(°C) | % Retention<br>Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| 160.00 | 110.00 | 94.48 | 79.05 | 67.80 | 60.25 | 54.94 | 51.01 |
| | 112.00 | 93.80 | 80.16 | 70.70 | 64.28 | 59.68 | 56.19 |
| | 114.00 | 92.86 | 80.65 | 72.59 | 67.09 | 63.07 | 59.98 |
| | 116.00 | 91.59 | 80.69 | 73.78 | 69.03 | 65.50 | 62.75 |
| | 118.00 | 89.93 | 80.35 | 74.46 | 70.35 | 67.25 | 64.79 |
| | 120.00 | 87.79 | 79.73 | 74.77 | 71.25 | 68.51 | 66.32 |
| | 122.00 | 85.09 | 78.86 | 74.81 | 71.81 | 69.41 | 67.43 |
| | 124.00 | 81.73 | 77.75 | 74.63 | 72.14 | 70.07 | 68.31 |
| | 126.00 | 77.71 | 76.47 | 74.31 | 72.32 | 70.56 | 69.01 |
| | 128.00 | 73.03 | 74.99 | 73.82 | 72.33 | 70.87 | 69.53 |
| | 130.00 | 67.86 | 73.35 | 73.22 | 72.23 | 71.08 | 69.92 |
| | 132.00 | 62.46 | 71.55 | 72.52 | 72.04 | 71.18 | 70.22 |
| | 134.00 | 57.13 | 69.60 | 71.72 | 71.76 | 71.19 | 70.43 |
| | 136.00 | 52.17 | 67.53 | 70.82 | 71.40 | 71.13 | 70.56 |
| | 138.00 | 47.78 | 65.37 | 69.86 | 70.98 | 71.01 | 70.63 |
| | 140.00 | 43.91 | 63.12 | 68.81 | 70.49 | 70.83 | 70.64 |
| 200.00 | 110.00 | 95.56 | 82.85 | 73.27 | 66.67 | 61.92 | 59.35 |
| | 112.00 | 95.01 | 83.78 | 75.76 | 70.21 | 66.16 | 63.05 |
| | 114.00 | 94.24 | 84.19 | 77.38 | 72.65 | 69.15 | 66.43 |
| | 116.00 | 93.21 | 84.21 | 78.39 | 74.32 | 71.27 | 68.86 |
| | 118.00 | 91.85 | 83.92 | 78.96 | 75.46 | 72.70 | 70.65 |
| | 120.00 | 90.08 | 83.39 | 79.22 | 76.22 | 73.80 | 71.98 |
| | 122.00 | 87.82 | 82.64 | 79.24 | 76.69 | 74.65 | 72.94 |
| | 124.00 | 84.96 | 81.69 | 79.08 | 76.97 | 75.21 | 73.69 |
| | 126.00 | 81.49 | 80.58 | 78.79 | 77.11 | 75.62 | 74.29 |
| | 128.00 | 77.33 | 79.29 | 78.36 | 77.11 | 75.88 | 74.74 |
| | 130.00 | 72.56 | 77.84 | 77.83 | 77.02 | 76.05 | 75.08 |
| | 132.00 | 67.42 | 76.24 | 77.20 | 76.85 | 76.13 | 75.33 |
| | 134.00 | 62.12 | 74.48 | 76.49 | 76.59 | 76.14 | 75.50 |
| | 136.00 | 57.00 | 72.59 | 75.69 | 76.26 | 76.07 | 75.60 |
| | 138.00 | 52.32 | 70.58 | 74.83 | 75.89 | 75.96 | 75.00 |
| | 140.00 | 48.13 | 68.45 | 73.97 | 75.45 | 75.79 | 75.66 |
| 240.00 | 110.00 | 96.29 | 85.49 | 77.17 | 71.32 | 67.06 | 63.83 |
| | 112.00 | 95.82 | 86.28 | 79.34 | 74.47 | 70.87 | 68.08 |
| | 114.00 | 95.18 | 86.63 | 80.75 | 76.62 | 73.53 | 71.11 |
| | 116.00 | 94.30 | 86.64 | 81.62 | 78.08 | 75.40 | 73.27 |
| | 118.00 | 93.15 | 86.39 | 82.11 | 79.07 | 76.73 | 74.85 |
| | 120.00 | 91.69 | 85.93 | 82.33 | 79.73 | 77.68 | 76.02 |
| | 122.00 | 89.70 | 85.27 | 82.35 | 80.14 | 78.36 | 76.86 |
| | 124.00 | 87.23 | 84.44 | 82.20 | 80.38 | 78.85 | 77.53 |
| | 126.00 | 84.17 | 83.47 | 81.94 | 80.58 | 79.20 | 78.05 |
| | 128.00 | 80.45 | 82.33 | 81.56 | 80.49 | 79.43 | 78.43 |
| | 130.00 | 76.09 | 81.04 | 81.09 | 80.41 | 79.57 | 78.73 |
| | 132.00 | 71.22 | 79.61 | 80.53 | 80.25 | 79.64 | 78.95 |
| | 134.00 | 66.06 | 78.02 | 79.89 | 80.02 | 79.69 | 79.09 |
| | 136.00 | 60.89 | 76.29 | 79.17 | 79.72 | 79.58 | 79.18 |
| | 138.00 | 56.05 | 74.44 | 78.30 | 79.39 | 79.48 | 79.23 |
| | 140.00 | 51.63 | 72.44 | 77.53 | 78.59 | 79.32 | 79.22 |

Table E- 27 Simulated quality retention of foods with thermal diffusivity 1.6x $10^{-7}$ $m^2/s$ after thermal processing in the elliptically shaped container #2, h = 300 w/$m^2$K

| D (min) | Temp(°C) | % Retention<br>Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| 40.00 | 110.00 | 80.21 | 40.53 | 22.64 | 14.48 | 10.22 | 7.73 |
| | 112.00 | 78.26 | 43.30 | 27.09 | 19.00 | 14.41 | 11.53 |
| | 114.00 | 75.48 | 44.68 | 30.25 | 22.58 | 17.95 | 14.90 |
| | 116.00 | 72.03 | 45.23 | 32.56 | 25.47 | 20.98 | 17.89 |
| | 118.00 | 67.76 | 45.02 | 34.06 | 27.62 | 23.37 | 20.35 |
| | 120.00 | 62.76 | 44.27 | 34.96 | 29.22 | 25.26 | 22.37 |
| | 122.00 | 57.11 | 43.07 | 35.36 | 30.32 | 26.71 | 23.97 |
| | 124.00 | 51.27 | 41.67 | 35.49 | 31.14 | 27.88 | 25.33 |
| | 126.00 | 45.47 | 40.04 | 35.34 | 31.67 | 28.76 | 26.42 |
| | 128.00 | 40.07 | 38.28 | 34.95 | 31.92 | 29.35 | 27.18 |
| | 130.00 | 35.40 | 36.51 | 34.46 | 32.07 | 29.85 | 27.90 |
| | 132.00 | 31.46 | 34.73 | 33.84 | 32.06 | 30.20 | 28.46 |
| | 134.00 | 28.23 | 33.02 | 33.15 | 31.96 | 30.44 | 28.91 |
| | 136.00 | 25.55 | 31.37 | 32.39 | 31.74 | 30.55 | 29.25 |
| | 138.00 | 23.34 | 29.82 | 31.60 | 31.45 | 30.59 | 29.49 |
| | 140.00 | 21.49 | 28.38 | 30.78 | 31.10 | 30.55 | 29.67 |
| 80.00 | 110.00 | 89.55 | 63.59 | 47.48 | 37.97 | 31.89 | 27.73 |
| | 112.00 | 88.44 | 65.69 | 51.90 | 43.46 | 37.85 | 33.87 |
| | 114.00 | 86.52 | 66.67 | 54.80 | 47.35 | 42.23 | 38.48 |
| | 116.00 | 84.74 | 66.99 | 56.79 | 50.24 | 45.61 | 42.14 |
| | 118.00 | 82.05 | 66.72 | 58.00 | 52.26 | 48.11 | 44.92 |
| | 120.00 | 78.70 | 65.89 | 58.67 | 53.69 | 49.98 | 47.07 |
| | 122.00 | 74.59 | 64.66 | 58.88 | 54.62 | 51.33 | 48.70 |
| | 124.00 | 69.87 | 63.51 | 58.85 | 55.27 | 52.48 | 50.02 |
| | 126.00 | 64.55 | 61.89 | 58.54 | 55.64 | 53.16 | 51.04 |
| | 128.00 | 58.87 | 60.06 | 58.02 | 55.75 | 53.64 | 51.73 |
| | 130.00 | 53.26 | 58.10 | 57.38 | 55.76 | 54.02 | 52.36 |
| | 132.00 | 47.96 | 56.02 | 56.59 | 55.61 | 54.25 | 52.83 |
| | 134.00 | 43.26 | 53.87 | 55.71 | 55.36 | 54.37 | 53.20 |
| | 136.00 | 39.16 | 51.86 | 54.72 | 55.00 | 54.38 | 53.44 |
| | 138.00 | 35.69 | 49.46 | 53.65 | 54.56 | 54.31 | 53.60 |
| | 140.00 | 32.77 | 47.30 | 52.54 | 54.04 | 54.15 | 53.68 |
| 120.00 | 110.00 | 92.98 | 73.93 | 60.84 | 52.40 | 46.65 | 42.51 |
| | 112.00 | 92.13 | 75.54 | 64.55 | 57.34 | 52.29 | 48.56 |
| | 114.00 | 91.00 | 76.27 | 66.91 | 60.70 | 56.24 | 52.66 |
| | 116.00 | 89.52 | 76.49 | 68.51 | 63.13 | 59.28 | 56.16 |
| | 118.00 | 87.58 | 76.24 | 69.45 | 64.80 | 61.33 | 58.60 |
| | 120.00 | 85.11 | 75.65 | 69.96 | 65.93 | 62.89 | 60.44 |
| | 122.00 | 81.99 | 74.72 | 70.09 | 66.69 | 64.01 | 61.82 |
| | 124.00 | 78.25 | 73.60 | 70.02 | 67.28 | 64.88 | 62.92 |
| | 126.00 | 73.82 | 72.23 | 69.73 | 67.47 | 65.49 | 63.76 |
| | 128.00 | 68.78 | 70.66 | 69.25 | 67.53 | 65.86 | 64.33 |
| | 130.00 | 63.39 | 68.93 | 68.67 | 67.49 | 66.15 | 64.83 |
| | 132.00 | 57.92 | 67.04 | 67.95 | 67.33 | 66.32 | 65.21 |
| | 134.00 | 52.70 | 65.04 | 67.14 | 67.09 | 66.39 | 65.49 |
| | 136.00 | 47.93 | 62.90 | 66.23 | 66.74 | 66.36 | 65.67 |
| | 138.00 | 43.74 | 60.69 | 65.23 | 66.32 | 66.27 | 65.78 |
| | 140.00 | 40.13 | 58.44 | 64.16 | 65.83 | 66.11 | 65.83 |

Table E- 27 —continued

| D (min) | Temp(°C) | % Retention<br>Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| 160.00 | 110.00 | 94.63 | 79.72 | 68.87 | 61.58 | 56.44 | 52.63 |
| | 112.00 | 94.04 | 81.01 | 71.59 | 65.66 | 61.48 | 58.15 |
| | 114.00 | 93.16 | 81.59 | 73.96 | 68.74 | 64.92 | 61.98 |
| | 116.00 | 92.02 | 81.76 | 75.27 | 70.79 | 67.46 | 64.85 |
| | 118.00 | 90.51 | 81.55 | 76.04 | 72.19 | 69.27 | 66.95 |
| | 120.00 | 88.56 | 81.05 | 76.44 | 73.14 | 70.59 | 68.52 |
| | 122.00 | 86.06 | 80.28 | 76.54 | 73.75 | 71.53 | 69.68 |
| | 124.00 | 83.00 | 79.34 | 76.46 | 74.16 | 72.24 | 70.61 |
| | 126.00 | 79.27 | 78.19 | 76.28 | 74.37 | 72.74 | 71.31 |
| | 128.00 | 74.86 | 76.84 | 75.76 | 74.46 | 73.05 | 71.78 |
| | 130.00 | 69.94 | 75.35 | 75.27 | 74.36 | 73.28 | 72.28 |
| | 132.00 | 64.66 | 73.69 | 74.65 | 74.21 | 73.40 | 72.58 |
| | 134.00 | 59.36 | 71.89 | 73.93 | 73.98 | 73.45 | 72.73 |
| | 136.00 | 54.29 | 69.95 | 73.12 | 73.67 | 73.42 | 72.87 |
| | 138.00 | 49.69 | 67.89 | 72.23 | 73.29 | 73.32 | 72.96 |
| | 140.00 | 45.63 | 65.74 | 71.27 | 72.86 | 73.17 | 72.98 |
| 200.00 | 110.00 | 95.68 | 83.42 | 74.28 | 67.84 | 63.27 | 59.84 |
| | 112.00 | 95.28 | 84.49 | 76.88 | 71.60 | 67.75 | 64.81 |
| | 114.00 | 94.49 | 84.97 | 78.55 | 74.08 | 70.77 | 66.19 |
| | 116.00 | 93.56 | 85.11 | 79.65 | 75.84 | 72.98 | 70.71 |
| | 118.00 | 92.32 | 84.93 | 80.38 | 77.03 | 74.53 | 72.53 |
| | 120.00 | 90.71 | 84.50 | 80.63 | 77.84 | 75.66 | 73.89 |
| | 122.00 | 88.63 | 83.84 | 80.71 | 78.35 | 76.46 | 74.89 |
| | 124.00 | 86.05 | 83.04 | 80.63 | 78.69 | 77.07 | 75.68 |
| | 126.00 | 82.84 | 82.05 | 80.48 | 78.87 | 77.49 | 76.28 |
| | 128.00 | 78.97 | 80.89 | 80.04 | 78.89 | 77.75 | 76.68 |
| | 130.00 | 74.58 | 79.58 | 79.59 | 78.84 | 77.94 | 77.03 |
| | 132.00 | 69.54 | 78.12 | 79.04 | 78.71 | 78.04 | 77.29 |
| | 134.00 | 64.36 | 76.52 | 78.41 | 78.58 | 78.08 | 77.48 |
| | 136.00 | 59.20 | 74.76 | 77.69 | 78.23 | 78.04 | 77.59 |
| | 138.00 | 54.37 | 72.86 | 76.90 | 77.89 | 77.95 | 77.66 |
| | 140.00 | 50.01 | 70.88 | 76.04 | 77.51 | 77.82 | 77.66 |
| 240.00 | 110.00 | 96.39 | 85.97 | 77.98 | 72.37 | 68.28 | 65.18 |
| | 112.00 | 95.98 | 86.90 | 80.32 | 75.78 | 72.29 | 69.66 |
| | 114.00 | 95.39 | 87.30 | 81.77 | 77.87 | 74.96 | 72.68 |
| | 116.00 | 94.60 | 87.42 | 82.72 | 79.41 | 76.90 | 74.91 |
| | 118.00 | 93.55 | 87.26 | 83.28 | 80.45 | 78.27 | 76.51 |
| | 120.00 | 92.18 | 86.89 | 83.56 | 81.15 | 79.25 | 77.78 |
| | 122.00 | 90.40 | 86.32 | 83.62 | 81.59 | 79.95 | 78.58 |
| | 124.00 | 88.17 | 85.62 | 83.55 | 81.88 | 80.47 | 79.27 |
| | 126.00 | 85.37 | 84.75 | 83.35 | 82.03 | 80.84 | 79.79 |
| | 128.00 | 81.93 | 83.73 | 83.03 | 82.04 | 81.00 | 80.13 |
| | 130.00 | 77.87 | 82.58 | 82.63 | 82.00 | 81.22 | 80.44 |
| | 132.00 | 73.24 | 81.28 | 82.14 | 81.88 | 81.31 | 80.66 |
| | 134.00 | 68.25 | 79.84 | 81.58 | 81.69 | 81.34 | 80.82 |
| | 136.00 | 63.13 | 78.25 | 80.94 | 81.44 | 81.30 | 80.92 |
| | 138.00 | 58.18 | 76.53 | 80.24 | 81.14 | 81.22 | 80.98 |
| | 140.00 | 53.63 | 74.68 | 79.46 | 80.66 | 81.10 | 80.99 |

Table E -28 Simulated quality retention of foods with thermal diffusivity 1.2x10$^{-7}$ m$^2$/s after thermal processing in the elliptically shaped container #2 using Infinite h

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| **D (min)** | **Temp(°C)** | **Z = 10°C** | **Z = 20°C** | **Z = 30°C** | **Z = 40°C** | **Z = 50°C** | **Z = 60°C** |
| 40.00 | 110.00 | 79.09 | 38.43 | 20.79 | 12.97 | 8.97 | 6.66 |
| | 112.00 | 76.54 | 40.51 | 24.53 | 16.79 | 12.48 | 9.82 |
| | 114.00 | 73.06 | 41.33 | 27.15 | 19.83 | 15.50 | 12.69 |
| | 116.00 | 66.65 | 41.25 | 28.89 | 22.15 | 17.96 | 15.13 |
| | 118.00 | 63.44 | 40.58 | 29.98 | 23.89 | 19.92 | 17.12 |
| | 120.00 | 57.43 | 39.35 | 30.49 | 25.10 | 21.42 | 18.76 |
| | 122.00 | 51.05 | 37.81 | 30.60 | 25.92 | 22.58 | 20.07 |
| | 124.00 | 44.75 | 36.05 | 30.40 | 26.42 | 23.43 | 21.11 |
| | 126.00 | 39.11 | 34.25 | 30.03 | 26.72 | 24.09 | 21.97 |
| | 128.00 | 34.30 | 32.42 | 29.48 | 26.81 | 24.54 | 22.63 |
| | 130.00 | 30.39 | 30.66 | 28.85 | 26.78 | 24.85 | 23.15 |
| | 132.00 | 27.17 | 28.97 | 28.11 | 26.58 | 24.97 | 23.45 |
| | 134.00 | 24.54 | 27.45 | 27.37 | 26.34 | 25.05 | 23.74 |
| | 136.00 | 22.26 | 26.00 | 26.57 | 26.00 | 25.02 | 23.91 |
| | 138.00 | 20.42 | 24.77 | 25.84 | 25.67 | 24.96 | 24.05 |
| | 140.00 | 18.81 | 23.62 | 25.10 | 25.27 | 24.83 | 24.11 |
| 80.00 | 110.00 | 89.91 | 64.87 | 45.43 | 35.87 | 29.82 | 25.71 |
| | 112.00 | 87.44 | 63.44 | 49.29 | 40.76 | 35.15 | 31.19 |
| | 114.00 | 85.37 | 63.97 | 51.78 | 44.25 | 39.13 | 35.42 |
| | 116.00 | 82.62 | 63.75 | 53.29 | 46.69 | 42.08 | 38.64 |
| | 118.00 | 79.15 | 63.01 | 54.16 | 48.40 | 44.26 | 41.09 |
| | 120.00 | 74.79 | 61.76 | 54.44 | 49.50 | 45.83 | 42.96 |
| | 122.00 | 69.61 | 60.15 | 54.33 | 50.18 | 46.96 | 44.39 |
| | 124.00 | 63.72 | 58.23 | 53.91 | 50.52 | 47.77 | 45.47 |
| | 126.00 | 57.54 | 56.13 | 53.28 | 50.65 | 48.33 | 46.32 |
| | 128.00 | 51.44 | 53.84 | 52.45 | 50.55 | 48.67 | 46.93 |
| | 130.00 | 45.92 | 51.47 | 51.49 | 50.30 | 48.85 | 47.39 |
| | 132.00 | 41.17 | 49.04 | 50.37 | 49.88 | 48.82 | 47.61 |
| | 134.00 | 37.25 | 46.65 | 49.20 | 49.39 | 48.75 | 47.81 |
| | 136.00 | 33.93 | 44.30 | 47.93 | 48.78 | 48.55 | 47.87 |
| | 138.00 | 31.18 | 42.13 | 46.67 | 48.15 | 48.31 | 47.80 |
| | 140.00 | 28.77 | 40.09 | 45.37 | 47.43 | 47.98 | 47.83 |
| 120.00 | 110.00 | 92.46 | 72.57 | 59.05 | 50.44 | 44.60 | 40.40 |
| | 112.00 | 91.43 | 73.78 | 62.33 | 54.91 | 49.75 | 45.95 |
| | 114.00 | 89.96 | 74.16 | 64.39 | 57.98 | 53.43 | 50.00 |
| | 116.00 | 87.99 | 73.95 | 65.61 | 60.07 | 56.06 | 52.96 |
| | 118.00 | 85.44 | 73.31 | 66.27 | 61.51 | 57.96 | 55.18 |
| | 120.00 | 82.14 | 72.26 | 66.45 | 62.40 | 59.31 | 56.83 |
| | 122.00 | 78.03 | 70.96 | 66.30 | 62.94 | 60.27 | 58.07 |
| | 124.00 | 73.09 | 69.20 | 65.88 | 63.18 | 60.92 | 58.99 |
| | 126.00 | 67.58 | 67.32 | 65.28 | 63.23 | 61.36 | 59.70 |
| | 128.00 | 61.48 | 65.21 | 64.40 | 63.09 | 61.61 | 60.20 |
| | 130.00 | 55.53 | 62.94 | 63.55 | 62.82 | 61.73 | 60.57 |
| | 132.00 | 50.02 | 60.52 | 62.47 | 62.38 | 61.66 | 60.73 |
| | 134.00 | 45.30 | 58.03 | 61.32 | 61.89 | 61.55 | 60.86 |
| | 136.00 | 41.28 | 55.47 | 60.03 | 61.27 | 61.32 | 60.96 |
| | 138.00 | 37.97 | 52.99 | 58.73 | 60.62 | 61.06 | 60.87 |
| | 140.00 | 35.10 | 50.55 | 57.34 | 59.89 | 60.71 | 60.77 |

Table E- 28 --continued

| D (min) | Temp(°C) | % Retention<br>Z = 10°C | Z = 20°C | Z = 30°C | Z = 60°C | Z = 60°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| 160.00 | 110.00 | 94.29 | 78.61 | 67.34 | 59.83 | 54.56 | 50.68 |
| | 112.00 | 93.50 | 79.58 | 70.12 | 63.76 | 59.22 | 55.75 |
| | 114.00 | 92.36 | 79.88 | 71.84 | 66.41 | 62.46 | 59.43 |
| | 116.00 | 90.83 | 79.69 | 72.84 | 68.19 | 64.75 | 62.07 |
| | 118.00 | 88.82 | 79.15 | 73.38 | 69.39 | 66.38 | 63.99 |
| | 120.00 | 86.18 | 78.26 | 73.51 | 70.14 | 67.53 | 65.41 |
| | 122.00 | 82.81 | 77.09 | 73.36 | 70.57 | 68.33 | 66.47 |
| | 124.00 | 78.64 | 75.65 | 72.97 | 70.75 | 68.87 | 67.25 |
| | 126.00 | 73.71 | 74.01 | 72.43 | 70.78 | 69.24 | 67.84 |
| | 128.00 | 68.12 | 72.14 | 71.72 | 70.63 | 69.43 | 68.26 |
| | 130.00 | 62.23 | 70.09 | 70.88 | 70.37 | 69.51 | 68.56 |
| | 132.00 | 56.44 | 67.84 | 69.90 | 69.97 | 69.44 | 68.69 |
| | 134.00 | 51.21 | 65.48 | 68.84 | 69.51 | 69.32 | 68.75 |
| | 136.00 | 46.67 | 62.97 | 67.65 | 68.95 | 69.10 | 68.79 |
| | 138.00 | 42.92 | 60.46 | 66.42 | 68.34 | 68.85 | 68.76 |
| | 140.00 | 39.71 | 57.92 | 65.89 | 67.66 | 68.52 | 68.66 |
| 200.00 | 110.00 | 95.40 | 82.48 | 72.88 | 68.29 | 61.57 | 58.03 |
| | 112.00 | 94.76 | 83.29 | 75.26 | 69.75 | 65.74 | 62.68 |
| | 114.00 | 93.84 | 83.54 | 76.73 | 72.85 | 68.61 | 65.94 |
| | 116.00 | 92.58 | 83.37 | 77.58 | 73.59 | 70.61 | 68.26 |
| | 118.00 | 90.93 | 82.90 | 76.83 | 74.62 | 72.03 | 69.94 |
| | 120.00 | 88.71 | 82.14 | 78.13 | 75.26 | 73.81 | 71.18 |
| | 122.00 | 85.89 | 81.12 | 77.99 | 75.62 | 73.70 | 72.18 |
| | 124.00 | 82.30 | 79.88 | 77.64 | 75.77 | 74.16 | 72.77 |
| | 126.00 | 77.94 | 78.44 | 77.16 | 75.77 | 74.47 | 73.28 |
| | 128.00 | 72.82 | 76.78 | 76.52 | 75.64 | 74.63 | 73.64 |
| | 130.00 | 67.18 | 74.94 | 75.78 | 75.40 | 74.69 | 73.89 |
| | 132.00 | 61.37 | 72.90 | 74.90 | 75.04 | 74.61 | 73.99 |
| | 134.00 | 55.88 | 70.71 | 73.94 | 74.62 | 74.50 | 74.07 |
| | 136.00 | 50.96 | 68.34 | 72.85 | 74.11 | 74.30 | 74.07 |
| | 138.00 | 46.84 | 65.91 | 71.72 | 73.56 | 74.87 | 74.03 |
| | 140.00 | 43.33 | 63.39 | 70.49 | 72.94 | 73.77 | 73.93 |
| 240.00 | 110.00 | 96.15 | 85.17 | 76.82 | 70.99 | 66.75 | 63.53 |
| | 112.00 | 95.61 | 85.66 | 78.91 | 74.06 | 70.50 | 67.75 |
| | 114.00 | 94.83 | 86.07 | 80.18 | 76.09 | 73.85 | 70.67 |
| | 116.00 | 93.77 | 85.92 | 80.92 | 77.43 | 74.81 | 72.74 |
| | 118.00 | 92.36 | 85.51 | 81.30 | 78.34 | 76.66 | 74.22 |
| | 120.00 | 90.48 | 84.84 | 81.38 | 78.99 | 76.93 | 75.31 |
| | 122.00 | 88.03 | 83.96 | 81.25 | 79.20 | 77.53 | 76.12 |
| | 124.00 | 84.89 | 82.86 | 80.94 | 79.32 | 77.92 | 76.71 |
| | 126.00 | 81.00 | 81.58 | 80.51 | 79.32 | 78.19 | 77.15 |
| | 128.00 | 76.31 | 80.11 | 79.94 | 79.19 | 78.33 | 77.47 |
| | 130.00 | 70.99 | 78.45 | 79.27 | 78.97 | 78.37 | 77.68 |
| | 132.00 | 65.29 | 76.59 | 78.48 | 78.65 | 78.30 | 77.77 |
| | 134.00 | 59.69 | 74.57 | 77.61 | 78.27 | 78.19 | 77.83 |
| | 136.00 | 54.51 | 72.36 | 76.63 | 77.81 | 78.01 | 77.82 |
| | 138.00 | 50.08 | 70.05 | 75.59 | 77.31 | 77.80 | 77.79 |
| | 140.00 | 46.32 | 67.62 | 74.46 | 76.74 | 77.53 | 77.70 |

Table E-29 Simulated quality retention of foods with thermal diffusivity $1.4\times10^{-7}$ $m^2/s$ after thermal processing in the elliptically shaped container #2 using infinite h

| | | % Retention | | | | | |
|---|---|---|---|---|---|---|---|
| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
| 40.00 | 110.00 | 79.75 | 40.18 | 22.57 | 14.56 | 10.36 | 7.90 |
| | 112.00 | 77.52 | 42.78 | 26.92 | 19.04 | 14.54 | 11.71 |
| | 114.00 | 74.39 | 43.96 | 31.00 | 22.60 | 18.12 | 15.15 |
| | 116.00 | 70.36 | 44.17 | 32.07 | 25.32 | 21.03 | 18.66 |
| | 118.00 | 65.38 | 43.60 | 33.31 | 27.28 | 23.28 | 20.42 |
| | 120.00 | 59.60 | 42.48 | 33.94 | 28.66 | 25.00 | 22.30 |
| | 122.00 | 53.38 | 41.03 | 34.18 | 29.60 | 26.28 | 23.74 |
| | 124.00 | 47.03 | 39.31 | 34.04 | 30.21 | 27.27 | 24.94 |
| | 126.00 | 41.08 | 37.41 | 33.63 | 30.52 | 27.97 | 25.86 |
| | 128.00 | 35.99 | 35.50 | 33.09 | 30.66 | 28.49 | 26.61 |
| | 130.00 | 31.75 | 33.59 | 32.39 | 30.60 | 28.81 | 27.17 |
| | 132.00 | 28.29 | 31.75 | 31.60 | 30.42 | 29.00 | 27.59 |
| | 134.00 | 25.43 | 30.01 | 30.74 | 30.12 | 29.06 | 27.88 |
| | 136.00 | 23.11 | 28.47 | 29.90 | 29.79 | 29.06 | 28.10 |
| | 138.00 | 21.13 | 27.05 | 29.05 | 29.39 | 28.97 | 28.23 |
| | 140.00 | 19.41 | 25.75 | 28.18 | 28.89 | 28.73 | 28.17 |
| 80.00 | 110.00 | 89.29 | 63.29 | 47.39 | 38.05 | 32.10 | 28.82 |
| | 112.00 | 88.01 | 65.24 | 51.70 | 43.47 | 38.00 | 34.11 |
| | 114.00 | 86.17 | 66.08 | 54.51 | 47.31 | 42.38 | 38.77 |
| | 116.00 | 83.70 | 66.10 | 56.28 | 50.02 | 45.62 | 42.31 |
| | 118.00 | 80.47 | 65.50 | 57.25 | 51.85 | 47.95 | 44.95 |
| | 120.00 | 76.42 | 64.41 | 57.65 | 53.00 | 49.63 | 46.94 |
| | 122.00 | 71.56 | 62.98 | 57.87 | 53.83 | 50.83 | 48.40 |
| | 124.00 | 65.95 | 61.23 | 57.36 | 54.26 | 51.71 | 49.56 |
| | 126.00 | 59.81 | 59.19 | 56.76 | 54.40 | 52.28 | 50.41 |
| | 128.00 | 53.66 | 57.01 | 56.01 | 54.37 | 52.67 | 51.07 |
| | 130.00 | 47.89 | 54.66 | 55.08 | 54.14 | 52.87 | 51.54 |
| | 132.00 | 42.85 | 52.22 | 54.01 | 53.78 | 52.92 | 51.88 |
| | 134.00 | 38.60 | 49.75 | 52.83 | 53.29 | 52.84 | 52.15 |
| | 136.00 | 35.14 | 47.37 | 51.61 | 52.74 | 52.69 | 52.17 |
| | 138.00 | 32.21 | 45.00 | 50.33 | 52.10 | 52.46 | 52.19 |
| | 140.00 | 29.87 | 42.88 | 48.98 | 51.36 | 52.07 | 52.03 |
| 120.00 | 110.00 | 92.72 | 73.69 | 60.75 | 52.47 | 46.85 | 42.80 |
| | 112.00 | 91.83 | 75.18 | 64.37 | 57.33 | 52.42 | 48.78 |
| | 114.00 | 90.53 | 75.79 | 66.66 | 60.65 | 56.37 | 53.13 |
| | 116.00 | 88.77 | 75.79 | 68.07 | 62.93 | 59.19 | 56.30 |
| | 118.00 | 86.42 | 75.28 | 68.81 | 64.43 | 61.17 | 58.61 |
| | 120.00 | 83.38 | 74.38 | 69.10 | 65.41 | 62.58 | 60.31 |
| | 122.00 | 79.66 | 73.18 | 69.08 | 66.01 | 63.57 | 61.55 |
| | 124.00 | 75.00 | 71.79 | 68.76 | 66.33 | 64.28 | 62.51 |
| | 126.00 | 69.66 | 69.93 | 68.21 | 66.40 | 64.72 | 63.21 |
| | 128.00 | 63.74 | 67.98 | 67.51 | 66.33 | 65.02 | 63.75 |
| | 130.00 | 57.71 | 65.81 | 66.65 | 66.09 | 65.15 | 64.11 |
| | 132.00 | 52.01 | 63.48 | 65.66 | 65.73 | 65.15 | 64.36 |
| | 134.00 | 46.95 | 61.02 | 64.54 | 65.25 | 65.05 | 64.49 |
| | 136.00 | 42.74 | 58.54 | 63.38 | 64.72 | 64.88 | 64.56 |
| | 138.00 | 39.28 | 56.01 | 62.08 | 64.11 | 64.64 | 64.55 |
| | 140.00 | 36.16 | 53.51 | 60.73 | 63.38 | 64.27 | 64.39 |

Table E- 29 --continued

| D (min) | Temp(°C) | % Retention<br>Z = 10°C | Z = 20°C | Z = 50°C | Z = 50°C | Z – 50°C | Z = 50°C |
|---|---|---|---|---|---|---|---|
| 160.00 | 110.00 | 94.49 | 79.53 | 68.80 | 61.64 | 56.61 | 52.90 |
| | 112.00 | 93.81 | 80.72 | 71.84 | 65.87 | 61.59 | 58.35 |
| | 114.00 | 92.80 | 81.20 | 73.74 | 68.70 | 65.03 | 62.21 |
| | 116.00 | 91.43 | 81.19 | 74.90 | 70.52 | 67.45 | 64.97 |
| | 118.00 | 89.59 | 80.76 | 75.50 | 71.87 | 69.13 | 66.96 |
| | 120.00 | 87.18 | 80.01 | 75.72 | 72.67 | 70.32 | 68.40 |
| | 122.00 | 84.11 | 79.00 | 75.67 | 73.16 | 71.14 | 69.44 |
| | 124.00 | 80.27 | 77.74 | 75.39 | 73.41 | 71.72 | 70.25 |
| | 126.00 | 75.59 | 76.23 | 74.90 | 73.46 | 72.09 | 70.84 |
| | 128.00 | 70.25 | 74.53 | 74.29 | 73.38 | 72.32 | 71.28 |
| | 130.00 | 64.42 | 72.61 | 73.53 | 73.15 | 72.41 | 71.58 |
| | 132.00 | 58.56 | 70.50 | 72.65 | 72.83 | 72.40 | 71.77 |
| | 134.00 | 53.08 | 68.22 | 71.65 | 72.40 | 72.30 | 71.87 |
| | 136.00 | 48.33 | 65.85 | 70.58 | 71.92 | 72.14 | 71.92 |
| | 138.00 | 44.31 | 63.38 | 69.42 | 71.36 | 71.91 | 71.90 |
| | 140.00 | 40.90 | 60.84 | 68.16 | 70.71 | 71.58 | 71.75 |
| 200.00 | 110.00 | 95.57 | 83.25 | 74.13 | 67.89 | 62.43 | 60.88 |
| | 112.00 | 95.01 | 84.25 | 76.74 | 71.59 | 67.85 | 64.98 |
| | 114.00 | 94.20 | 84.64 | 78.36 | 74.04 | 70.80 | 68.39 |
| | 116.00 | 93.08 | 84.62 | 79.33 | 75.69 | 72.96 | 70.81 |
| | 118.00 | 91.57 | 84.26 | 79.84 | 76.76 | 74.41 | 72.53 |
| | 120.00 | 89.56 | 83.61 | 80.01 | 77.43 | 75.43 | 73.78 |
| | 122.00 | 86.99 | 82.75 | 79.96 | 77.84 | 76.13 | 74.68 |
| | 124.00 | 83.71 | 81.67 | 79.71 | 78.05 | 76.62 | 75.37 |
| | 126.00 | 79.62 | 80.35 | 79.28 | 78.08 | 76.93 | 75.86 |
| | 128.00 | 74.79 | 78.87 | 78.75 | 78.00 | 77.12 | 76.24 |
| | 130.00 | 69.31 | 77.17 | 78.88 | 77.80 | 77.19 | 76.49 |
| | 132.00 | 63.53 | 75.28 | 77.29 | 77.51 | 77.17 | 76.65 |
| | 134.00 | 57.86 | 73.20 | 78.40 | 77.13 | 77.08 | 76.73 |
| | 136.00 | 52.77 | 71.00 | 75.45 | 76.70 | 76.93 | 76.77 |
| | 138.00 | 48.36 | 68.66 | 74.39 | 76.20 | 76.73 | 76.74 |
| | 140.00 | 44.63 | 66.20 | 73.24 | 75.61 | 76.43 | 76.61 |
| 240.00 | 110.00 | 96.29 | 85.83 | 77.92 | 72.41 | 68.42 | 65.40 |
| | 112.00 | 95.82 | 86.68 | 80.20 | 75.69 | 72.37 | 69.82 |
| | 114.00 | 95.14 | 87.02 | 81.60 | 77.84 | 75.04 | 72.80 |
| | 116.00 | 94.19 | 87.00 | 82.44 | 79.27 | 76.89 | 75.00 |
| | 118.00 | 92.91 | 86.68 | 82.88 | 80.20 | 78.16 | 76.51 |
| | 120.00 | 91.20 | 86.12 | 83.02 | 80.79 | 79.04 | 77.61 |
| | 122.00 | 88.99 | 85.37 | 82.97 | 81.14 | 79.65 | 78.39 |
| | 124.00 | 86.13 | 84.42 | 82.75 | 81.32 | 80.08 | 78.99 |
| | 126.00 | 82.51 | 83.26 | 82.37 | 81.34 | 80.34 | 79.42 |
| | 128.00 | 78.13 | 81.95 | 81.89 | 81.26 | 80.51 | 79.75 |
| | 130.00 | 73.03 | 80.43 | 81.29 | 81.08 | 80.57 | 79.96 |
| | 132.00 | 67.44 | 78.73 | 80.60 | 80.82 | 80.55 | 80.10 |
| | 134.00 | 61.75 | 76.84 | 79.80 | 80.48 | 80.45 | 80.17 |
| | 136.00 | 56.43 | 74.81 | 78.94 | 80.09 | 80.32 | 80.19 |
| | 138.00 | 51.73 | 72.62 | 77.96 | 79.64 | 80.14 | 80.17 |
| | 140.00 | 47.71 | 70.28 | 76.94 | 79.12 | 79.87 | 80.05 |

Table E-30 Simulated quality retention of foods with thermal diffusivity 1.6x $10^{-7}$ $m^2/s$ after thermal processing in the elliptically shaped container #2 using Infinite h

| D (min) | Temp(°C) | % Retention<br>Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| 40.00 | 110.00 | 80.32 | 41.68 | 24.13 | 15.97 | 11.61 | 9.01 |
| | 112.00 | 78.26 | 44.53 | 28.87 | 20.93 | 16.33 | 13.40 |
| | 114.00 | 75.39 | 46.05 | 32.33 | 24.93 | 20.38 | 17.31 |
| | 116.00 | 71.69 | 46.56 | 34.74 | 28.03 | 23.70 | 20.67 |
| | 118.00 | 68.98 | 46.16 | 36.17 | 30.22 | 26.21 | 23.31 |
| | 120.00 | 61.49 | 45.22 | 36.98 | 31.80 | 28.16 | 25.44 |
| | 122.00 | 55.30 | 43.77 | 37.23 | 32.83 | 29.59 | 27.08 |
| | 124.00 | 48.99 | 42.11 | 37.19 | 33.54 | 30.70 | 28.42 |
| | 126.00 | 42.93 | 40.23 | 36.84 | 33.90 | 31.43 | 29.35 |
| | 128.00 | 37.49 | 38.21 | 36.24 | 34.01 | 31.95 | 30.12 |
| | 130.00 | 33.03 | 36.24 | 35.55 | 34.00 | 32.33 | 30.75 |
| | 132.00 | 29.37 | 34.29 | 34.73 | 33.83 | 32.54 | 31.20 |
| | 134.00 | 26.32 | 32.40 | 33.80 | 33.50 | 32.59 | 31.50 |
| | 136.00 | 23.86 | 30.70 | 32.89 | 33.13 | 32.58 | 31.73 |
| | 138.00 | 21.77 | 29.13 | 31.94 | 32.69 | 32.68 | 31.86 |
| | 140.00 | 19.97 | 27.70 | 30.99 | 32.18 | 32.29 | 31.90 |
| 80.00 | 110.00 | 89.61 | 64.45 | 49.03 | 39.88 | 34.00 | 29.96 |
| | 112.00 | 88.44 | 66.61 | 53.59 | 45.62 | 40.31 | 36.51 |
| | 114.00 | 86.77 | 67.67 | 56.66 | 49.75 | 44.99 | 41.49 |
| | 116.00 | 84.52 | 67.95 | 58.68 | 52.71 | 48.49 | 45.31 |
| | 118.00 | 81.53 | 67.51 | 59.76 | 54.66 | 50.95 | 48.09 |
| | 120.00 | 77.78 | 66.62 | 60.32 | 56.01 | 52.77 | 50.21 |
| | 122.00 | 73.14 | 65.28 | 60.38 | 56.82 | 54.04 | 51.76 |
| | 124.00 | 67.78 | 63.68 | 60.17 | 57.34 | 54.98 | 52.99 |
| | 126.00 | 61.82 | 61.79 | 59.68 | 57.53 | 55.57 | 53.81 |
| | 128.00 | 55.59 | 59.64 | 58.95 | 57.50 | 55.95 | 54.46 |
| | 130.00 | 49.70 | 57.38 | 58.09 | 57.34 | 56.19 | 54.97 |
| | 132.00 | 44.43 | 54.99 | 57.08 | 57.02 | 56.28 | 55.31 |
| | 134.00 | 39.92 | 52.50 | 55.92 | 56.55 | 56.21 | 55.51 |
| | 136.00 | 36.24 | 50.06 | 54.72 | 56.02 | 56.08 | 55.63 |
| | 138.00 | 33.14 | 47.66 | 53.44 | 55.40 | 55.85 | 55.66 |
| | 140.00 | 30.49 | 45.35 | 52.09 | 54.69 | 55.54 | 55.61 |
| 120.00 | 110.00 | 92.94 | 74.62 | 62.15 | 54.15 | 48.69 | 44.75 |
| | 112.00 | 92.13 | 76.24 | 65.93 | 59.22 | 54.53 | 51.05 |
| | 114.00 | 90.95 | 77.03 | 68.42 | 62.74 | 58.67 | 55.59 |
| | 116.00 | 89.36 | 77.22 | 70.00 | 65.18 | 61.67 | 58.95 |
| | 118.00 | 87.20 | 76.85 | 70.85 | 66.77 | 63.73 | 61.33 |
| | 120.00 | 84.42 | 76.12 | 71.25 | 67.86 | 65.22 | 63.11 |
| | 122.00 | 80.85 | 75.02 | 71.26 | 68.47 | 66.24 | 64.39 |
| | 124.00 | 76.53 | 73.69 | 71.05 | 68.86 | 67.00 | 65.40 |
| | 126.00 | 71.41 | 72.08 | 70.60 | 68.98 | 67.45 | 66.06 |
| | 128.00 | 65.63 | 70.22 | 69.95 | 68.92 | 67.74 | 66.57 |
| | 130.00 | 59.68 | 68.20 | 69.18 | 68.74 | 67.91 | 66.97 |
| | 132.00 | 53.86 | 65.98 | 68.27 | 68.44 | 67.95 | 67.23 |
| | 134.00 | 48.54 | 63.59 | 67.21 | 68.00 | 67.86 | 67.37 |
| | 136.00 | 44.07 | 61.14 | 66.09 | 67.50 | 67.72 | 67.45 |
| | 138.00 | 40.32 | 58.63 | 64.87 | 66.92 | 67.49 | 67.45 |
| | 140.00 | 37.15 | 56.09 | 63.57 | 66.27 | 67.20 | 67.38 |

Table E- 30 --continued

| D (min) | Temp(°C) | Z = 10°C | Z = 20°C | Z = 30°C | Z = 40°C | Z = 50°C | Z = 60°C |
|---|---|---|---|---|---|---|---|
| | | % Retention | | | | | |
| 160.00 | 110.00 | 94.66 | 80.28 | 69.59 | 63.11 | 58.28 | 54.71 |
| | 112.00 | 94.03 | 81.58 | 73.15 | 67.49 | 63.44 | 60.39 |
| | 114.00 | 93.13 | 82.28 | 75.28 | 70.47 | 67.02 | 64.36 |
| | 116.00 | 91.90 | 82.34 | 76.50 | 72.52 | 69.56 | 67.25 |
| | 118.00 | 90.21 | 82.03 | 77.18 | 73.83 | 71.30 | 69.28 |
| | 120.00 | 88.00 | 81.43 | 77.50 | 74.71 | 72.54 | 70.78 |
| | 122.00 | 85.13 | 80.51 | 77.49 | 75.22 | 73.38 | 71.85 |
| | 124.00 | 81.56 | 79.39 | 77.30 | 75.52 | 74.00 | 72.68 |
| | 126.00 | 77.18 | 78.04 | 76.91 | 75.61 | 74.37 | 73.23 |
| | 128.00 | 72.01 | 76.44 | 76.34 | 75.54 | 74.60 | 73.65 |
| | 130.00 | 66.34 | 74.67 | 75.67 | 75.38 | 74.73 | 73.97 |
| | 132.00 | 60.48 | 72.71 | 74.87 | 75.11 | 74.75 | 74.18 |
| | 134.00 | 54.83 | 70.53 | 73.94 | 74.72 | 74.66 | 74.29 |
| | 136.00 | 49.84 | 68.25 | 72.95 | 74.28 | 74.53 | 74.34 |
| | 138.00 | 45.58 | 65.85 | 71.85 | 73.77 | 74.33 | 74.33 |
| | 140.00 | 41.98 | 63.35 | 70.67 | 73.18 | 74.06 | 74.26 |
| 200.00 | 110.00 | 95.70 | 83.88 | 75.16 | 69.19 | 64.92 | 61.71 |
| | 112.00 | 95.28 | 84.96 | 77.86 | 73.01 | 69.48 | 66.79 |
| | 114.00 | 94.46 | 85.48 | 79.60 | 75.57 | 72.60 | 70.29 |
| | 116.00 | 93.46 | 85.59 | 80.69 | 77.32 | 74.79 | 72.80 |
| | 118.00 | 92.07 | 85.32 | 81.26 | 78.43 | 76.27 | 74.54 |
| | 120.00 | 90.25 | 84.81 | 81.52 | 79.17 | 77.33 | 75.83 |
| | 122.00 | 87.85 | 84.03 | 81.51 | 79.60 | 78.05 | 76.74 |
| | 124.00 | 84.82 | 83.07 | 81.34 | 79.85 | 78.57 | 77.45 |
| | 126.00 | 81.02 | 81.91 | 80.98 | 79.92 | 78.88 | 77.92 |
| | 128.00 | 76.40 | 80.52 | 80.50 | 79.85 | 79.07 | 78.27 |
| | 130.00 | 71.14 | 78.97 | 79.91 | 79.71 | 79.17 | 78.54 |
| | 132.00 | 65.45 | 77.22 | 79.22 | 79.46 | 79.18 | 78.72 |
| | 134.00 | 59.70 | 75.27 | 78.40 | 79.12 | 79.10 | 78.80 |
| | 136.00 | 54.41 | 73.18 | 77.51 | 78.73 | 78.98 | 78.84 |
| | 138.00 | 49.77 | 70.94 | 76.54 | 78.28 | 78.80 | 78.83 |
| | 140.00 | 45.82 | 68.57 | 75.47 | 77.76 | 78.56 | 78.76 |
| 240.00 | 110.00 | 96.41 | 86.37 | 78.82 | 73.57 | 69.76 | 66.88 |
| | 112.00 | 95.98 | 87.30 | 81.18 | 76.93 | 73.82 | 71.43 |
| | 114.00 | 95.36 | 87.74 | 82.68 | 79.17 | 76.57 | 74.53 |
| | 116.00 | 94.51 | 87.83 | 83.62 | 80.69 | 78.45 | 76.75 |
| | 118.00 | 93.34 | 87.60 | 84.11 | 81.66 | 79.75 | 78.28 |
| | 120.00 | 91.79 | 87.15 | 84.33 | 82.30 | 80.71 | 79.40 |
| | 122.00 | 89.73 | 86.47 | 84.31 | 82.67 | 81.33 | 80.20 |
| | 124.00 | 87.18 | 85.64 | 84.16 | 82.88 | 81.78 | 80.81 |
| | 126.00 | 83.75 | 84.62 | 83.85 | 82.94 | 82.04 | 81.21 |
| | 128.00 | 79.66 | 83.48 | 83.42 | 82.87 | 82.20 | 81.52 |
| | 130.00 | 74.75 | 83.03 | 82.90 | 82.74 | 82.29 | 81.75 |
| | 132.00 | 69.32 | 80.47 | 82.28 | 82.52 | 82.30 | 81.90 |
| | 134.00 | 63.62 | 78.70 | 81.56 | 82.22 | 82.22 | 81.97 |
| | 136.00 | 58.16 | 76.80 | 80.77 | 81.88 | 82.11 | 82.00 |
| | 138.00 | 53.24 | 74.73 | 79.89 | 81.47 | 81.95 | 81.99 |
| | 140.00 | 49.90 | 72.50 | 78.93 | 81.01 | 81.74 | 81.93 |

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# BIOGRAPHICAL SKETCH

Punpen Pornchaloempong was born on October 19, 1965 in, Rayong, Thailand. She obtained her bachelor's degree in agro-industrial product development from the Department of Product Development, Kasetsart University, Bangkok, Thailand, in 1985 and obtained her masters from the same department in 1987. She has been a faculty member in the Department of Food Engineering at King Mongkut Institute of Technology Lardkrabang, Thailand, since her graduation. Punpen earned a Fulbright scholarship and Delta Gamma Kappa World Fellowship award for her Ph.D. study at the University of Florida.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy

M Balaban

Murat O. Balaban, Chair
Professor of Food Science and Human Nutrition

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy

Arthur A. Teixeira

Arthur A. Teixeira, Cochair
Professor of Agricultural and Biological Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy

Khe V. Chau.

Khe V. Chau
Professor of Agricultural and Biological Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy

Charles A. Sims
Professor of Food Science and Human Nutrition

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy

John A. Cornell

John A. Cornell
Professor of Statistics

This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy

August, 1999

Dean, College of Agriculture

Dean, Graduate School